qnde

Review of Progress in Quantitative Nondestructive Evaluation

E-Book of Abstracts

41st Annual Review of Progress in Quantitative Nondestructive Evaluation Conference

Boise Centre
Boise, Idaho
July 20-25, 2014

Organized by

Center for Nondestructive Evaluation
Iowa State University

In cooperation with

American Society for Nondestructive Testing
National Science Foundation Industry/University Cooperative Research Centers

CENTER FOR NDE

2014 Review of Progress in Quantitative NDE Program Summary
Boise Centre - Boise, Idaho

	8:30 am	9:00	10:10	11:00	12:10 pm	1:00	2:00	3:10	4:00	5:00	6:00	7:00	8:00	9:00
			Break					Break						
Saturday July 19		World Federation of NDE Centers Two Day Short Course “Imaging in NDE Methods” Sponsored by World Federation of NDE Centers Organizer: Prof. U. Ewert from BAM in Berlin, Germany Location: Salmon/Snake with lunch in Payette												
Sunday July 20		World Federation of NDE Centers Two Day Short Course (9:15 am-5:30 pm each day)					**Conference check-in and registration** **Meadow** **2:00-6:00 pm and 7:00-9:00 pm**					***Welcome Reception*** ***Meadow*** ***7:00 -9:00 pm***		
Monday July 21	Plenary 1: Dr. Alfred Hero and Dr. Nico F. Declercq Plenary 2: Dr. Mathias Fink and Dr. Ivan Pelivanov *Hawk (8:45 am-12:15 pm)*				**LUNCH** ***Eagle***	3. Guided Waves I – *Peregrines* 4. Thermography – *Cottonwoods-Firs* 5. Additive Manufacturing I – *Pines-Willows* 6. Electromagnetics Eddy Current – *Salmon-Snake*					***By Invitation*** *World Federation of NDE Centers* *Board Meeting/Buffet Dinner*			
Tuesday July 22	7. Phased Arrays I – *Peregrines* 8. Civil Structures & Concrete – *Pines-Willows* 9. Radiography I – *Cottonwoods-Firs* 10. Noncontact and Optical – *Salmon-Snake*					11. Student Poster Competition; Guided Waves, Surface Waves, Fundamentals, NDE Sensors and Systems *Hawk*		12. Phased Arrays II – *Peregrines* 13. THz NDE – *Salmon-Snake* 14. Nuclear Reactors I – *Cottonwoods-Firs* 15. Additive Mfg. II – *Pines-Willows*			***QNDE Conference Dinner*** ***Eagle*** ***Social Reception at 6:30 pm*** ***Dinner at 7:00 pm***			
Wednesday July 23	16. Guided Waves II-Modelling – *Peregrines* 17. Nuclear Reactors II – *Cottonwoods-Firs* 18. Uncertainty/Reliability of NDE – *Pines-Willows* 19. Nonlinear Ultrasonics – *Salmon-Snake*					20. Guided Waves III – *Peregrines* 21. Composites I – *Pines-Willows* 22. Microstructure – *Cottonwoods-Firs* 23. Structural Health Monitoring – *Salmon-Snake*						***By Invitation*** *CNDE Sponsor Reception*		
Thursday July 24	24. Materials Characterization – *Peregrines* 25. Laser Ultrasonics – *Cottonwoods-Firs* 26. Composites II – *Pines-Willows* 27. Modelling – *Salmon-Snake*					28. Posters: Ultrasonic Characterization, Ultrasonics, Materials Characterization, Signal Processing, Advanced Materials, Composites *Hawk*		29. Radiography II – *Cottonwoods-Firs* 30. Signal Processing – *Peregrines* 31. Robotics – *Pines-Willows* 32. Nonlinear – *Salmon-Snake*			***5K FUN RUN*** ***6:30 pm*** ***Boise River Greenbelt***			
Friday July 25	33. Composites III – *Cottonwoods-Firs* 34. Benchmark – *Pines* 35. UT Measurements – *Willows* 36. Eddy Current – *Salmon-Snake* *Conference Adjourns at 10:30 am*													

MONDAY

MONDAY AFTERNOON, JULY 21, 2014

These grid pages are provided for planning purposes. As you go through the program to decide which talks/sessions you would like to attend, you can mark them on this grid for a one shot look at where you would like to go and when on each day of the conference.

	Session 3 **Guided Waves I** ***Peregrines***	**Session 4** **Thermography** ***Cottonwoods-Firs***	**Session 5** **Additive Manufacturing I** ***Pines-Willows***	**Session 6** **Electromagnetics** **Eddy Current** ***Salmon-Snake***
1:30 PM				
1:50				
2:10				
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3:10	COFFEE BREAK			
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5:30	ADJOURN			

Plenary Sessions 1 and 2

qnde

Review of Progress in Quantitative Nondestructive Evaluation

Boise Centre
Boise, Idaho
July 20 – 25, 2014

PROGRAM

Monday, July 21, 2014

PLENARY SESSION 1
Leonard J. Bond, Chairperson
Hawk

8:45 AM **Opening Remarks**
---**Leonard J. Bond**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Welcome to Boise
---**Harold Blackman**, Associate Vice President for Strategic Research Initiatives for the Division of Research and Economic Development, Boise State University, 1910 University Drive, Boise, ID 83725

9:00 AM **Sparsity Regularized Image Reconstruction**
---**Alfred Hero**, University of Michigan, 1301 Beal Street, Ann Arbor, MI 48109-2122

9:50 AM **Ultrasonic Imaging of Materials Under Unconventional Circumstances**
---**Nico Felicien Declercq**, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta GA & UMI Georgia Tech – CNRS 2958, Georgia Tech Lorraine, Metz, France

10:25 AM ***Break***

PLENARY SESSION 2
Dale E. Chimenti, Chairperson
Hawk

10:40 AM **Acoustic Imaging with Time Reversal Methods: From Medicine to NDT**
---**Mathias Fink**, Institut Langevin, Ecole Supérieure de Physique et de Chimie Industrielles de la Ville de Paris, 1 rue Jussieu, Paris, 75005, France

11:30 AM **Non-Destructive Evaluation of Fiber-Reinforced Composites with a Fast 2D Fiber-Optic Laser-Ultrasound Scanner**
---**Ivan Pelivanov**[1,2], Jinjun Xia[1], C.-W. Wei[1], Matthew O'Donnell[1], Takashi Buma[3], [1]Departments of Bioengineering, University of Washington, Seattle, WA; [2]International Laser Center, Moscow State University, Moscow, Russian Federation; [3]Union College, Schenectady, NY 12301

12:15 PM ***Lunch***

Please Note: The bolded authors throughout this program indicate the presenting author. Also, 40 minute opening presentations are bolded in blue.

9:00 AM

Sparsity Regularized Image Reconstruction
---**Alfred Hero**, University of Michigan, 1301 Beal Street, Ann Arbor, MI 48109-2122

---Image reconstruction is an inverse problem that is often under-constrained due to insufficient number of projections, high noise, or uncertainties in the forward operator. In such cases one must regularize the problem by constraining the image or the uncertainty in the forward operator. Smoothness and sparsity constraints are often used to accomplish the needed regularization. This presentation will cover the concepts underlying sparsity constrained image reconstruction in the context of sub-surface microscopy and related applications.

9:50 AM

Ultrasonic Imaging of Materials Under Unconventional Circumstances
---**Nico Felicien Declercq**, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta GA & UMI Georgia Tech – CNRS 2958, Georgia Tech Lorraine, Metz, France

---“Ultrasonic Imaging of materials” covers a wide technological area with main purpose to look at and to peek inside materials. In an ideal world one would manage to examine materials like a clairvoyant. Fortunately this is impossible hence nature has offered sufficient challenges to mankind to provoke curiosity and to develop science and technology. Here we focus on the appearance of certain undesired physical effects that prohibit direct imaging of materials in ultrasonic C-scans. Furthermore we try to make use of these effects to obtain indirect images of materials and therefore make a virtue of necessity. First we return to one of the oldest quests in the progress of mankind: how thick is ice? Our ancestors must have faced this question early on during migration to Northern Europe and to the America’s and Asia. If a physicist or engineer is not provided with helpful tools such as a drill or a device based on ultrasound, it is difficult to determine the ice thickness. Guided waves, similar to those used for nondestructive testing of thin plates in structural health monitoring can be used in combination with the human ear to determine the thickness of ice. To continue with plates, if an image of its interior is desired high frequency ultrasonic pulses can be applied. It is known by the physicist that the resolution depends on the wavelength and that high frequencies usually result in undesirably high damping effects inhibiting deep penetration into the material. To the more practical oriented engineer it is known that it is advantageous to polish surfaces before examination because scattering and diffraction of sound lowers the image resolution. Random scatterers cause some blurriness but cooperating scatters, causing coherent diffraction effects similar to the effects that cause DVD’s to show rainbow patterns under sunlight, can cause spooky images and erroneous measurements of material properties. However when properly understood, diffraction effects, for instance if one has no other options but to work with frequencies that are fortuitously very effectively diffracted by the surface structure of a material under investigation, can be used to obtain high contract images or to obtain information that would normally be hidden from standard C-scan techniques. Similar contrast enhancement is also obtained for oblique C-scans of composites. The presentation will further focus on non-conventional uses of conventional techniques and instruments to improve ultrasonic imaging of materials under non-ideal circumstances.---Research is presented done in collaboration with Declercq’s PhD students Peter McKeon, Jingfei Liu, Anurupa Shaw, Rayisa Moiseyenko, Qi Wang, and Junliang Dong with financial support from the Region of Lorraine, l’ Agence Nationale de la Recherche ANR and le Centre National de la Recherche Scientifique CNRS.

10:40 AM

Acoustic Imaging with Time-Reversal Methods: From Medicine to NDT
---**Mathias Fink**, Institut Langevin, Ecole Supérieure de Physique et de Chimie Industrielles de la Ville de Paris, 1 rue Jussieu, Paris, 75005, France

---This talk will present an overview of the research conducted on ultrasonic time-reversal methods applied to biomedical imaging and to non-destructive testing. We will first describe iterative time-reversal techniques that allow both focusing ultrasonic waves on reflectors in tissues (kidney stones, micro-calcifications, contrast agents) or on flaws in solid materials. We will also show that time-reversal focusing does not need the presence of bright reflectors but it can be achieved only from the speckle noise generated by random distributions of non-resolved scatterers. We will describe the applications of this concept to correct distortions and aberrations in ultrasonic imaging and in NDT. In the second part of the talk we will describe the concept of time-reversal processors to get ultrafast ultrasonic images with typical frame rates of order of 10.000 F/s. It is the field of ultrafast ultrasonic imaging that has plenty medical applications and can be of great interest in NDT. We will describe some applications in the biomedical domain: Quantitative Elasticity imaging of tissues by following shear wave propagation to improve cancer detection and Ultrafast Doppler imaging that allows ultrasonic functional imaging.

11:30 AM

Non-Destructive Evaluation of Fiber-Reinforced Composites with a Fast 2D Fiber-Optic Laser-Ultrasound Scanner

---**Ivan Pelivanov**[1,2], Jinjun Xia[1], C.-W. Wei[1], Matthew O'Donnell[1], Takashi Buma[3], [1]Departments of Bioeningeering, University of Washington, Seattle, WA; [2]International Laser Center, Moscow State University, Moscow, Russian Federation; [3]Union College, Schenectady, NY

---Laser ultrasonic (LU) inspection represents an attractive, non-contact method to evaluate composite materials. Current non-contact systems, however, have relatively low sensitivity compared to contact piezoelectric detection. They are also difficult to adjust, very expensive, and strongly influenced by environmental noise. Here, we demonstrate that most of these drawbacks can be eliminated by combining a new generation of compact, inexpensive fiber lasers with new developments in fiber telecommunication optics and an optimally designed balanced probe scheme. In particular, a new type of a balanced fiber-optic Sagnac interferometer is presented as part of an all-optical LU pump-probe system for high speed non-destructive testing and evaluation (NDT&E) of aircraft composites. The performance of the LU system is demonstrated on a number of composite samples typically used in aircraft industry. Wide-band ultrasound probe signals are generated directly at the sample surface with a pulsed fiber laser delivering nanosecond laser pulses at a 1 kHz repetition rate with a pulse energy of only 0.6 mJ. A balanced fiber-optic Sagnac interferometer is employed to detect pressure signals in a 1–10 MHz frequency range at the same point (an 8 μm focal spot) on the composite surface. A fast (up to 100 mm/s) 2D translation system is employed to move the sample during scanning and produce a complete B-scan consisting of a thousand A-scans in less than a second. Results obtained with the Sagnac interferometer are compared to those made with a contact wide-band PVDF transducer. The sensitivity of this system, in terms of the noise equivalent pressure, is found to be only 10 dB above the Nyquist thermal noise limit. To our knowledge, this is the best reported sensitivity for a non-contact ultrasonic detector of this dimension.

Session 3

SESSION 3
GUIDED WAVES I
Peter Cawley and Ronald A. Roberts, Co-Chairpersons
Peregrines

1:30 PM **1-D Profiling Using Highly Dispersive Guided Waves**
---**Arno Volker**, Tim van Zon, Daniel Enthoven, and Wesley Verburg, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek or TNO (Netherlands Organisation for Applied Scientific Research), Stieltjesweg 1, 2600 AD Delft, The Netherlands

1:50 PM **Helical Path Separation for Guided Wave Tomography**
---**Peter Huthwaite,** Imperial College London, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

2:10 PM **Large Scale Implementation of Guided Wave Based Broken Rail Monitoring**
---Francois A. Burger, Institute for Maritime Technology, South Africa; **Philip W. Loveday** and Craig S. Long, CSIR Material Science and Manufacturing, South Africa

2:30 PM **Investigation of Guided Wave Propagation in Pipes Buried in Sand**
---**Eli Leinov**, Peter Cawley, and Michael Lowe, Imperial College, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

2:50 PM **High-Frequency Guided Waves for Corrosion Monitoring**
---Daniel Chew and **Paul Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

3:10 PM ***Break***

3:30 PM **Crack Depth Profiling Using Guided Wave Angle Dependent Reflectivity**
---**Arno Volker**, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek or TNO (Netherlands Organisation for Applied Scientific Research), Pooria Pahlavan and Gerrit Blacquiere, TNO, Stieltjesweg 1, 2600 AD Delft, The Netherlands

3:50 PM **High Frequency Guided Waves for Hidden Fatigue Crack Growth Monitoring in Multi-Layer Aerospace Structures**
---Henry Chan and **Paul Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

4:10 PM **On the Measurement of Guided Wavefields Via Air-Coupled Ultrasonic Transducers**
---**Jennifer E. Michaels** and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

4:30 PM **Incremental Scattering of Guided Waves from a Notch Originating at a Through-Hole**
---**Xin Chen**, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

4:50 PM **Topological Imaging of Defects in Anisotropic Plates**
---S. Rodriguez, Cooperative Research Centre for Advanced Composite Structures Ltd., 506 Lorimer Street, Fishermans Bend, Victoria, 3207, Australia; E. Ducasse, M. Castaings, and **M. Deschamps**, Univ. Bordeaux, I2M, UMR 5295, F-33400 Talence, France, Arts et Métiers ParisTech, I2M, UMR 5295, F-33400, Talence, France

1:30 PM

1-D Profiling Using Highly Dispersive Guided Waves
---**Arno Volker**, Tim van Zon, Daniel Enthoven, and Wesley Verburg, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek or TNO (Netherlands Organisation for Applied Scientific Research), Stieltjesweg 1, 2600 AD Delft, The Netherlands

---Corrosion is one of the industries major issues regarding the integrity of assets. Currently inspections are conducted at regular intervals to ensure a sufficient integrity level of these assets. Cost reduction while maintaining a high level of reliability and safety of installations is a major challenge. There are many situations where the actual defect location is not accessible, e.g., a pipe support or a partially buried pipe. Guided wave tomography has been developed to reconstruct the wall thickness. In case of bottom of the line corrosion, i.e., a single corrosion pit, a simpler approach may be followed. Data is collected in a pit-catch configuration at the 12 o’clock position using highly dispersive guided waves. The phase spectrum is used to invert for a wall thickness profile in the circumferential direction, assuming a Gaussian defect profile. An EMAT sensor design has been made to measure at the 12 o’clock position of a pipe. The concept is evaluated on measured data, showing good sizing capabilities on a variety simple defect profiles.

1:50 PM

Helical Path Separation for Guided Wave Tomography
---**Peter Huthwaite**, Imperial College London, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---The quantification of wall loss caused by corrosion is a significant challenge for the petrochemical industry. Corrosion commonly occurs at pipe supports, limiting surface access for inspection; guided wave tomography is presented as a solution. Guided waves are transmitted across the region of interest between a pair of ring arrays. The thickness can then be reconstructed by quantitative imaging algorithms, making the assumption that the pipe wall can be unwrapped to a flat plate with two parallel arrays. The cyclical nature of the pipe, however, causes problems since waves between any pair of send-receive transducers can travel along an infinite number of helical paths around the pipe, so any received component will be a superposition of many wave components. This presentation will outline a solution to enable the components from different paths to be separated, allowing tomographic methods to subsequently be applied. The approach is demonstrated with experimental data, con firming that the technique is robust to both systematic and uncorrelated experimental uncertainties, and able to accurately and reliably separate the different components, which can then be used to generate thickness reconstructions.

2:10 PM

Large Scale Implementation of Guided Wave Based Broken Rail Monitoring
---Francois A. Burger, Institute for Maritime Technology, South Africa; **Philip W. Loveday** and Craig S. Long, CSIR Material Science and Manufacturing, South Africa

---A guided wave ultrasound system has been developed over the past 17 years to detect breaks in continuously welded rail track. Installation of the system on an 846 km long heavy duty freight line was conducted between January 2013 and June 2014 and this implementation will be presented. The system operates in pitch – catch mode with alternate transmit and receive transducers spaced approximately 1km apart. If the acoustic signal is not received at the receive station an alarm is triggered to indicate a break in the rail between the transmit station and the receive station. The system is permanently installed, powered by solar panels and issues broken rail alarms using the GSM network where available, and digital radio technology in other areas. The entire length of rail is interrogated every fifteen minutes. While the system concept is simple obtaining false alarm free operation has presented a considerable challenge. Techniques had to be developed to deal with the large variations in signal propagation that occur with temperature changes, between different sections of rail and over time as the rail ages. The transducers had to comply with the environmental specifications for track mounted equipment to ensure reliable operation while the electronics had to be hardened to survive in the hostile EMI environment with lightening and traction induced surges. In spite of these efforts equipment failures do occur but the system design layout ensures that these failures are detected and do not result in false alarms. The underlying guided wave physics will only be briefly described with the presentation focusing on system design, implementation, integration with the rail operator’s systems, performance achieved and remaining challenges.

2:30 PM

Investigation of Guided Wave Propagation in Pipes Buried in Sand
---**Eli Leinov**, Peter Cawley, and Michael Lowe, Imperial College, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

---Long-range ultrasonic guided wave testing of pipelines is used routinely for detection of corrosion defects in a variety of industries, e.g. petrochemical and energy. When the method is applied to pipelines that are buried in soil, test ranges tend to be significantly compromised compared to those achieved for pipelines above ground because of the attenuation of the guided wave, due to energy leaking into the embedding soil. The attenuation characteristics of guided wave propagation in a pipe buried in sand are investigated using a full scale experimental rig. The apparatus consists of an 8"-diameter, 6-meters long steel pipe embedded over 3 meters in a rectangular container filled with sand and fitted with an air-bladder for the application of overburden pressure. Measurements of the attenuation of the T(0,1) and L(0,2) guided wave modes over a range of sand conditions, including loose, compacted, water saturated and drained, are presented. Attenuation values are found to be in the range of 1-5.5 dB/m. The application of overburden pressure modifies the compaction of the sand and increases the attenuation. The attenuation decreases in the fully water-saturated sand, while it increases in drained sand to values comparable with those obtained for the compacted sand. The attenuation behavior of the torsional guided wave mode is found not to be captured by a uniform soil model; comparison with predictions obtained with the DISPERSE software suggest that this is likely to be due to a layer of sand adhering to the surface of the pipe.

2:50 PM

High-Frequency Guided Waves for Corrosion Monitoring
---Daniel Chew and **Paul Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

---Adverse environmental conditions can lead to corrosion during the life cycle of industrial structures, e.g., offshore oil platforms, ships, and desalination plants. Both pitting corrosion and generalized corrosion leading to wall thickness loss can cause the degradation of the integrity and load bearing capacity of the structure. Monitoring of corrosion damage in difficult to access areas can be achieved using high frequency guided waves propagating along the structure from accessible areas. Using standard ultrasonic transducers with single sided access to the structure, high frequency guided wave modes were generated that penetrate through the complete thickness of the structure. Wall thickness reduction was induced using accelerated corrosion in a salt water bath. The corrosion damage was monitored based on the effect on the wave propagation and interference of the different modes. The change in the wave interference was quantified based on an analysis in the frequency domain (Fourier transform) and was found to match well with theoretical predictions for the wall thickness loss. The scattering of the guided wave modes at simulated (milled) pitting corrosion defects was investigated experimentally using pulse-echo and laser interferometer measurements. The sensitivity for the detection of hidden pitting corrosion with single sided access was verified. High frequency guided waves have the potential for corrosion damage monitoring at critical and difficult to access locations from a stand-off distance.

3:30 PM

Crack Depth Profiling Using Guided Wave Angle Dependent Reflectivity
---**Arno Volker**, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek or TNO (Netherlands Organisation for Applied Scientific Research), Pooria Pahlavan, and Gerrit Blacquiere, TNO, Stieltjesweg 1, 2600 AD Delft, The Netherlands

---Tomographic corrosion monitoring techniques have been developed, using two rings of sensors around the circumference of a pipe. This technique is capable of providing a detailed wall thickness map. This concept is expanded to detect and size cracks and small corrosion defects like root corrosion. The expanded concept also uses two arrays of guided-wave transducers, collecting both reflection and transmission data. The data is processed such that the angle-dependent reflectivity is obtained without using a baseline signal of a defect-free situation. The angle-dependent reflectivity is the input of an inversion scheme that calculates a crack depth profile. From this profile, the depth and length of the crack can be determined. Preliminary experiments show encouraging results. The depth sizing accuracy is in the order of 0.5 mm.

3:50 PM

High Frequency Guided Waves for Hidden Fatigue Crack Growth Monitoring in Multi-Layer Aerospace Structures

---Henry Chan and **Paul Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

---Varying loading conditions of aircraft structures result in stress concentration at fastener holes, where multi-layered components are connected, possibly leading to the development of fatigue cracks. High frequency guided waves propagating along the structure allow for the non-destructive testing of such components, e.g., aircraft wings. However, the sensitivity for the detection of small, potentially hidden, fatigue cracks has to be ascertained. The type of multi-layered model structure investigated consists of two adhesively bonded aluminum plate-strips. Fatigue experiments were carried out. The sensitivity of the high frequency guided wave modes to monitor fatigue crack growth at a fastener hole during cyclic loading was investigated, using both standard pulse-echo equipment and laser interferometry. The sensitivity and repeatability of the measurements were ascertained, having the potential for fatigue crack growth monitoring at critical and difficult to access fastener locations from a stand-off distance. The robustness of the methodology for practical in-situ ultrasonic monitoring of fatigue crack growth is discussed.

4:10 PM

On the Measurement of Guided Wavefields Via Air-Coupled Ultrasonic Transducers

---**Jennifer E. Michaels** and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

---Guided wavefields are now routinely acquired with scanning laser vibrometers for both characterization of guided wave propagation and damage detection. However, such measurements are time-consuming, particularly for imaging of large areas, primarily because of the degree of signal averaging required to reduce incoherent noise. A scanned air-coupled transducer is an alternative wavefield acquisition method that is based upon recording the very small amplitude pressure waves that leak into air from the out-of-plane motion of the guided wavefield. Air-coupled methods are attractive because they are not sensitive to small variations in optical reflectivity and special surface preparations are thus not necessary. In addition, not as much averaging is needed, making the acquisition process much faster. Unlike laser vibrometry, the recorded signals are not a direct measure of the propagating guided waves, but experiments have shown that the acquired wavefields resemble those obtained from laser-based systems. For the work presented here, data were recorded with both methods for the same aluminum plates and composite panels. Signals are analyzed and compared in terms of signal-to-noise ratio, modal content, frequency response, and effect of spatial spot size. Although signals are not identical, it is shown that air-coupled transducers provide a robust alternative to laser methods.

4:30 PM

Incremental Scattering of Guided Waves from a Notch Originating at a Through-Hole

---**Xin Chen**, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

---Cracks, which frequently initiate from fastener holes as a result of stress concentration, are one of the most common defects in metallic plate-like structures. Among a variety of methods for crack detection, ultrasonic guided waves have been shown to be effective. To examine the performance of guided wave methods in the laboratory, notches are often used to simulate cracks. While extensive research has focused on the scattering of guided waves from a notch as well as a hole, limited work has been done on the incremental scattering resulting from the addition of a notch to an existing hole. This scenario is of particular interest for in situ monitoring of fastener holes, where the goal is to detect changes in scattering caused by crack initiation and growth. An experimental approach is taken here where a broadband chirp excitation is applied to surface-mounted PZT transducers to generate guided waves in an aluminum plate, and the out-of-plane particle motion is measured by a laser vibrometer. Notches are introduced at a through-hole, and the corresponding far field scattering information is obtained from full-circle laser scans taken before and after introduction of the notch. The laser received signals are then filtered to generate equivalent responses to narrowband tone burst excitations at different center frequencies. Angular scattering patterns are presented and the mode and frequency dependence of the scattering is discussed.

4:50 PM

Topological Imaging of Defects in Anisotropic Plates
---S. Rodriguez, Cooperative Research Centre for Advanced Composite Structures Ltd., 506 Lorimer Street, Fishermans Bend, Victoria, 3207, Australia; E. Ducasse, M. Castaings, and **M. Deschamps**, Univ. Bordeaux, I2M, UMR 5295, F-33400 Talence, France, Arts et Métiers ParisTech, I2M, UMR 5295, F-33400, Talence, France

---The complexity of wave propagation in anisotropic waveguides makes imaging their defects challenging. In order to propose an appropriate solution to this problem, this complexity is first studied for the plate under investigation and a physical interpretation of phenomena is given. More specifically, the diffraction of a guided wave mode by a local defect in a unidirectional carbon epoxy composite plate is numerically investigated. The effects of frequency-dependent (dispersion) and angle-dependent (anisotropy) velocities like horns are discussed. Then, it is demonstrated that such complexity is not an obstacle to the application of the topological imaging which is aimed in the current work. The method is first applied to a fully numerical case consisting of an epoxy plate having 3 through-thickness holes and insonified by a plane guided wavefront. As the complex propagation is properly taken into account in both simulations required to build the topological image, the three defects are accurately located in the plate. Then, as a first experimental application on an anisotropic plate, a [0,90,45,-45]2s carbon epoxy plate which has been locally damaged by two impacts is investigated. Using an efficient semi-analytical simulation and a linear transducer array, both damages are accurately located from a single ultrasonic illumination of the plate sample and about 10 seconds of numerical computation. The experimental results are compared with the classical time-consuming immersion C-scan.---This work was undertaken within the Systems Development for Structural Health Monitoring project, part of a CRC-ACS (Cooperative Research Centre for Advanced Composite Structures) research program, established and supported under the Australian Government’s Cooperative Research Centers Program. The experimental set-up was funded by the Conseil Régional d’Aquitaine, France.

Session 4

SESSION 4
THERMOGRAPHY
Xiaoyan Han and Stephen D. Holland, Co-Chairpersons
Cottonwoods-Firs

1:30 PM **Determination of Delamination Size from Thermographic Data**
---**William P. Winfree**, Patricia A. Howell, and Joseph N. Zalameda, NASA Langley Research Center, Research Directorate, Hampton, VA 23681

1:50 PM **Thermographic Inspection of Pipes, Tanks, and Containment Liners**
---**Jeremy Renshaw[1]**, Nathan Muthu[1], James R. Lhota[2], and Steven M. Shepard[2]; [1]Electric Power Research Institute, Charlotte, NC 28262; [2]Thermal Wave Imaging Inc., Ferndale, MI 48220-2308

2:10 PM **Thermal and Destructive Interrogation of Ceramic Matrix Composites**
---**Greg C. Ojard**, United Technologies Research Center, Measurement Sciences, East Hartfotrd, CT 06108; Douglas Doza and Paul Angel, NASA, Glenn Research Center, Cleveland, OH; Zhong Ouyang and Imelda Smyth, Pratt & Whitney, Materials Processing and Engineering, East Hartford, CT; Unni Santhosh and Jalees Ahmad, Structural Analytics, Carlsbad, CA; Yasser Gowayed, Auburn University, Auburn, AL 36830

2:30 PM **The Application of Model-Based Analysis to Thermographic NDE Data**
---**K. Elliott Cramer**, Patricia A. Howell, and Eric R. Burke, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA 23681; J. Seebo, Analytical Mechanics Associates, Inc.; NASA Langley Research Center, Hampton, VA 23681

2:50 PM **Scanning Induction Thermography (SIT) for Imaging Damages in Carbon-Fiber Reinforced Plastics (CFRP) Components**
---Renil Thomas Kidangan and **Krishnan Balasubramaniam**, Centre for Non-Destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-600036, Tamil Nadu, India

3:10 PM ***Break***

3:30 PM **Evaluation of Thermal Properties from Non-Contact Acousto-Thermal Signature (NCATS) Analysis**
---Matthew Cherry and John T. Welter, Materials State Awarness and Supportability Branch, AFRL, WPAFB, Dayton, OH 45469; Amanda Criner, Norm Schehl, and **Shamachary Sathish**, Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469

3:50 PM **Effects of Mounting and Exciter Coupling on Vibrothermographic NDE**
---**Jyani Vaddi**, Gabriel Murray, and Stephen D. Holland, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:10 PM **Ultrasonic Vibrothermography Using Low-Power Actuators: An Impact Damage Detection Case Study**
---**Benjamin Lamboul**, Jean-Michel Roche, and Françoise Passilly, Onera - The French Aerospace Lab, F92322 Châtillon, France; Daniel Balageas, I2M/TREFLE Laboratory, F-33400 Talence, France

4:30 PM **Effect of Structures in Composites on Widespread Impact Damage Detection with Sonic Infrared Imaging**
---**Xiaoyan Han**, Justin M. Ar-Rasheed, and A. Lubowicki, Department of Electrical and Computer Engineering, Wayne State University, 5050 Anthony Wayne Drive, Detroit, MI 48202

4:50 PM **Thermal Scanning Probe Microscopy for High Resolution Material Characterization**
---**Bernd Kohler**, Martin Kuttner, Yvonne Standke, Malgorzata Kopycinska-Muller, and Martin Gall, Fraunhofer IKTS-MD, Dresden, Germany; Pavel Janus, Institute of Electron Technology, Warszawa, Poland; Theodor Gotszalk, Wroclaw University of Technology, 50-137 Wroclaw, Poland

1:30 PM

Determination of Delamination Size from Thermographic Data
---**William P. Winfree**, Patricia A. Howell, and Joseph N. Zalameda, NASA Langley Research Center, Research Directorate, Hampton, VA 23681

---Conventional methods for reducing the pulsed thermographic responses of delaminations tend to overestimate the size of the delamination, since the heat diffuses in the plane parallel to the surface. The result is temperature profile over the delamination is larger than the delamination size. A variation method is presented for reducing the thermographic data to produce an estimated size for the delamination that is much closer to the true size of the delamination. The size is determined from both the temporal and spatial thermal response of the exterior surface above the delamination and constraints on the length of the contour surrounding the delamination. Examples of the application of the technique to simulation and experimental data acquired are presented to investigate the limitations of the technique.

1:50 PM

Thermographic Inspection of Pipes, Tanks, and Containment Liners
---**Jeremy Renshaw**[1], Nathan Muthu[1], James R. Lhota[2], and Steven M. Shepard[2]; [1]Electric Power Research Institute, Charlotte, NC 28262; [2]Thermal Wave Imaging Inc., Ferndale, MI 48220-2308

---Nuclear power plants are required to operate at a high level of safety. Recent industry and license renewal commitments aim to further increase safety by requiring the inspection of components that have not traditionally undergone detailed inspected in the past, such as tanks and liners. NEI 09-14 requires the inspection of buried pipes and tanks while containment liner inspections are required as a part of license renewal commitments. Containment liner inspections must inspect the carbon steel liner for defects – such as corrosion – that could threaten the pressure boundary and ideally, should be able to inspect the surrounding concrete for foreign material that could be in contact with the steel liner. This requires a simultaneous inspection of two materials with very different properties. Rapid, yet detailed, inspection results are required due to the massive size of the tanks and containment liners to be inspected. For this reason, thermal NDE methods were evaluated to inspect tank and containment liner mockups with simulated defects. Thermographic Signal Reconstruction (TSR) was utilized to enhance the images and provide detailed information on the sizes and depths of the observed defects. The results show that thermographic inspection is highly sensitive to the defects of interest and is capable of rapidly inspecting large areas.

2:10 PM

Thermal and Destructive Interrogation of Ceramic Matrix Composites
---**Greg C. Ojard**, United Technologies Research Center, Measurement Sciences, East Hartfotrd, CT 06108; Douglas Doza and Paul Angel, NASA, Glenn Research Center, Cleveland, OH; Zhong Ouyang and Imelda Smyth, Pratt & Whitney, Materials Processing and Engineering, East Hartford, CT; Unni Santhosh and Jalees Ahmad, Structural Analytics, Carlsbad, CA; Yasser Gowayed, Auburn University, Auburn, AL

---Ceramic matrix composites are intended for elevated temperature use and their performance at temperature must be clearly understood as insertion efforts are to be realized. Most efforts to understand ceramic matrix composites at temperature are based on their lifetime at temperature under stress based on fatigue or creep testing or residual testing after some combination of temperature, stress and time. While these efforts can be insightful especially based on their mechanical performance, there is no insight into how other properties are changing with thermal exposure. To gain additional insight into oxidation behavior of CMC samples, a series of fatigue and creep samples tested at two different temperatures were non-destructively interrogated after achieving run-out conditions by multiple thermal methods and limited X-ray CT. After non-destructive analysis, residual tensile tests were undertaken at room temperature. The resulting residual properties will be compared against the non-destructive data. Analysis will be done to see if data trends can be determined to use the data for prediction of mechanical and thermal properties.

2:30 PM

The Application of Model-Based Analysis to Thermographic NDE Data
---**K. Elliott Cramer**, Patricia A. Howell, and Eric R. Burke, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA 23681; J. Seebo, Analytical Mechanics Associates, Inc.; NASA Langley Research Center, Hampton, VA 23681

---As the use of composite materials increase, inspection for manufacturing anomalies and in-service damage is becoming essential. Infrared (IR) thermography has been used extensively as a large area, rapid inspection technology for composite structures. This inspection process can result in very large data sets that can be difficult and time consuming to interrogate. This paper will demonstrate how a multilayer computational heat diffusion model is used to quickly reduce and quantify defects in large volumes of thermographic data. Results from the application of this technique to flash IR data, totaling approximately 100GB, acquired during a large composite test article inspection are presented. A comparison of this approach with traditional data analysis techniques and a description of the automated large area inspection system are also given.

2:50 PM

Scanning Induction Thermography (SIT) for Imaging Damages in Carbon-Fiber Reinforced Plastics (CFRP) Components

---Renil Thomas Kidangan and **Krishnan Balasubramaniam**, Centre for Non-Destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-600036, Tamil Nadu, India

---Tone burst eddy current technique (TBET) has been earlier demonstrated for metallic components for the detection of cracks, corrosion, etc. Carbon fiber reinforced composites are increasing being used as replacement to metals for load-bearing components, particularly in the aerospace industries. The major advantage of thermography over other techniques is the potential for the rapid inspection of a large area within a short time. In Scanning Induction Thermography (SIT) technique, the induction coil is moved over the sample at optimal speeds and the temperature developed is measured as a function of time and distance using an IR camera. SIT is a new hybrid, non-contact and non-destructive technique which uses induced eddy currents (where the coil and the test sample move relative to each other) to heat the material being tested and defect detection is based on the changes of the induced eddy current flows revealed by the thermal contrast captured by an Infrared camera. Even though Carbon-Fiber Reinforced Plastics (CFRP) has a relatively less electrical conductivity compared to metals, it was observed that measurable heat could be generated using scanning induction heating that can be used for nondestructive evaluation. A 2-D anisotropic transient eddy current heating and thermal conduction model has been developed in order to study the effect of speed of the coil motion and verified using experiments. Several CFRP components were evaluated for detection of impact damage, location of stiffeners and disbonds using the SIT technique. The effect of EMI/Lightning Protection metallic mesh on the SIT has also been explored with studies on the mesh sizes, depth of embedment, etc.

3:30 PM

Evaluation of Thermal Properties from Non-Contact Acousto-Thermal Signature (NCATS) Analysis

---Mathew Cherry and John T. Welter, Materials State Awarness and Supportability Branch, AFRL, WPAFB, Dayton, OH 45469; Amanda Criner, Norm Schehl, and **Shamachary Sathish**, Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469

---Non-contact acousto-thermal signature (NCATS) is a measure of the efficiency of the material to convert acoustic energy to heat. In a polycrystalline material several physical mechanisms are responsible for the conversion of mechanical energy to heat. These include excitation frequency and amplitude, grain structure and dislocation based internal friction contributions, and thermoelastic effects. These phenomena have been proposed as the drivers of thermal excitation during NCATS experiments, but the assumptions have not been tested and a comprehensive theoretical model has not been developed. The cooling portion of the NCATS experiment is governed solely by diffusion phenomenon with Newton's law of cooling at the boundary of the specimen. It is proposed that this later portion of the heating curve could be used to estimate thermal diffusivity and cooling parameters independently of the complex heating mechanisms during the early portion of the curve. Additionally, the final temperature distribution in the sample after heating is provided as input to the diffusion model for the later of the curve, and could be estimated with diffusivity and cooling parameters as well. This gives a means of validation from one portion of the problem to another and could offer insight into the heating mechanisms during mechanical excitation. One difficulty in all of NCATS measurements is that the temperature rise is so small that discretization rate becomes an issue. This leads to a combination of random measurement error and digitization error which is considered censored data. This paper describes a method to determine the thermal diffusivity, cooling constants and initial temperature distribution of Ti-6Al-4V from NCATS data by using the expectation-maximization (EM) algorithm (a popular method for dealing with censored data). The data obtained for the initial temperature distribution will be used to analyze the assumptions made about heating in the part during acoustic excitation.

3:50 PM

Effects of Mounting and Exciter Coupling on Vibrothermographic NDE
---**Jyani Vaddi,** Gabriel Murray, and Stephen D. Holland, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Vibrothermography, also known as Sonic IR and Thermosonics, is notoriously sensitive to extrinsic parameters such as specimen mounting and transducer coupling. This is a result of the complicated resonances which deliver vibrational energy and allow the crack to heat up. We present an approximate theory which explains how the mechanical mounting and transducer coupling affect the resonances of the specimen, and compare this theory with simulation and experiment. Based on these explanations we suggest guidelines to assist practitioners in minimizing the sensitivity of their vibrothermography tests to specimen mounting and transducer coupling.---This material is based on work supported by the Air Force Research Laboratory under Contract #FA8650-10-D-5210, Task Order #023, and performed at Iowa State University. Case # 88ABW-2014-2749.

4:10 PM

Ultrasonic Vibrothermography Using Low-Power Actuators: An Impact Damage Detection Case Study

---**Benjamin Lamboul**, Jean-Michel Roche, and Françoise Passilly, Onera - The French Aerospace Lab, F92322 Châtillon, France; Daniel Balageas, I2M / TREFLE Laboratory, F-33400 Talence, France

---Ultrasonic vibrothermography is an NDT technique based on the conversion of periodic mechanical solicitations (vibrations) into heat by defects. The mechanisms of heat production are not always readily identified, and may vary from one application to another. Heat generation is usually attributed to rubbing or clapping of free surfaces in the defect, and enhanced viscoelastic dissipation. In standard applications of the technique, ultrasonic excitation is achieved with a high input power (up to 2 kW) sonotrode coupled to the sample under examination. Although very effective, the coupling of such mechanical power combined with localized heating effects at the application point are not always desirable, depending on the material of the intended NDT application. In the perspective of finding alternatives for such cases, the present paper investigates the possibility of using low-power actuators for vibrothermographic acquisition techniques. Our chosen case study is the detection of an impact defect in a 4 mm-thick carbon-fiber composite plate. The actuators used are piezoelectric discs bonded to the plate surface and vibrating in radial mode. The frequency of excitation is set in a range from tens to a few hundred kHz to generate Lamb waves (A0 and S0 modes) in the plate. A modulation signal (typically 0.1 Hz) is applied to the excitation signal to perform lock-in detection on the surface temperature signals collected by a middle-wavelength infrared camera. The paper reports the defect signatures obtained from different parameter combinations (excitation and modulation frequencies, amplitude of the excitation signal, and actuator-to-defect distances), along with a reference flash thermography signature performed on the same sample. The adverse effect of heat diffusion from the piezoelectric discs is highlighted as well as the type of mechanical stress yielding the best defect signatures (based on the dominant Lamb mode generated at a given frequency). The paper finally discusses the minimum level of actuator power required to achieve a good detection of the considered impact damage, for a given detection distance.

4:30 PM

Effect of Structures in Composites on Widespread Impact Damage Detection with Sonic Infrared Imaging

---**Xiaoyan Han**, Justin M. Ar-Rasheed, and A. Lubowicki, Department of Electrical and Computer Engineering, Wayne State University, 5050 Anthony Wayne Drive, Detroit, MI 48202

---Composite materials offer a wide choice of matrix and reinforcements for various applications that span from marine to automotive and aerospace applications. The wide choice of reinforcements and matrices also offer cost advantages for specific applications where semi-structural and structural parts can be manufactured to meet performance requirements. For those reasons, composites have provided themselves broad applications in various industries. However, materials such as carbon fiber composites (CFC) has strength weakness, in which if damage, such as delamination, occurs, it could be deadly in critical structures like in aircraft if it's not identified in time. Sonic IR Imaging has shown its capability as a fast, wide area NDE method. We have been studying widespread impact damages (WSID) in composite structures and evaluating how structures affect thermal signatures in defect characterization. In this paper, we will present our results on composite samples which contain different structures.

4:50 PM

Thermal Scanning Probe Microscopy for High Resolution Material Characterization

---**Bernd Köhler**, Martin Küttner, Yvonne Standke, Malgorzata Kopycinska-Müller, and Martin Gall, Fraunhofer IKTS-MD, Dresden, Germany; Pavel Janus, Institute of Electron Technology, Warszawa, Poland; Theodor Gotszalk, Wroclaw University of Technology, 50-137 Wroclaw, Poland

---Rapid progress of micro- and nano-electronic components technology is directly related to even more remarkable progress of tools for advanced process and process control as well as of new materials development. This progress has to be furthermore supported by an adequate development of tools for process/device monitoring and characterization. Today, there is a shortage of appropriate characterization approaches especially for thermal characterization of interconnects in electronic devices on the nanoscale. Up to now the temperatures are estimated by numerical modelling only, there is no established way of measurement. The paper reports the progress of the European project: Scanning Thermal Microscopy for Beyond CMOS/More-than-Moore devices characterization. One of the project demonstration tasks is described more closely which is the monitoring of self-heating of a sub 100 nm interconnect in a nano-electronic device. Tips for scanning thermal microscopy are designed and produced in the consortium. To reduce thermal mass and increase the electrical resistance of the tip a post processing by focused ion beam (FIB) machining is introduced. Both effects contribute to an increase thermal sensitivity as confirmed by modelling. Modelling is essential for understanding the measurement. The sample under consideration has been modeled in its thermal properties. This model includes the electrical currents and allows describing the self-heating process. For point measurements of the temperature dependent electrical resistance give results consistent with the modelling results.

Session 5

SESSION 5

ADDITIVE MANUFACTURING I

Regor L. Saulsberry and Eric R. Burke, Co-Chairpersons

Pines-Willows

1:30 PM **Summary of NDE of Additive Manufacturing Efforts in NASA**
---Jess M. Waller, Kenneth L. Hodges, Karen H. B. Taminger, Bradford H. Parker, and **Regor L. Saulsberry**, NASA White Sands Test Facility, NASA Goddard Space Flight Center, Las Cruces, NM 88004-0020

2:10 PM **Near-Infrared Machine Vision and NDE for Additive Manufacturing**
---**Eric Burke** and Joseph Zalameda, NASA Langley Research Center, NASA LaRC B1230, Rm. 151, MS231, Hampton, VA 23681-2199

2:30 PM **A Study of Internal Structure in Components Made by Additive Manufacturing Process Using 3D X-Ray Tomography**
---Raguvarun K[1], Krishnan Balasubramaniam[1], and **Prabhu Rajagopal[1]**, [1]IIT Madras, Centre for Nondestructive Evaluation, Chennai 600036, T.N., India; Suresh Palanisamy[2,4] and Romesh Nagarajah[2], [2]Swinburne University of Technology, Faculty of Engineering, Science and Technology, Hawthorn, VIC 3122, Australia; Nicholas Hoye[3,4] and Dominic Curiri[3,4], [3]University of Wollongong, Faculty of Engineering, NSW 2522, Australia; [4]Defence Materials Technology Centre, Hawthorn, VIC 3122, Australia

2:50 PM **Online Layer-Wise Ultrasonic Non-Destructive Certification of an Ultrasonic Additive Manufacturing System for Closed Loop Control Applications**
---**Venkata Karthik Nadimpalli**, John S. D. Jangam, Deepankar Pal, and Brent E. Stucker, Department of Industrial Engineering, J. B. Speed School of Engineering, University of Louisville, Louisville, KY 40217; Jeong K. Na, Aerospace Group, Wyle Research Laboratories, 2700 Indian Ripple Road, Dayton, OH 45401

3:10 PM ***Break***

3:30 PM **Overview of Additive Manufacturing Activities at MTU Aero Engines**
---**Joachim Bamberg**, Karl-Heinz Dusel, and Wilhelm Satzger, MTU Aero Engines, Manufacturing Technology, Munich, Germany

3:50 PM **Process Monitoring of Additive Manufacturing by Using Optical Tomography**
---**Guenter Zenzinger**, Joachim Bamberg, T. Hess, and Alexander Ladewig, MTU Aero Engines, Manufacturing Technology, Munich, Germany

4:10 PM **Monitoring System for the Quality Assessment in Additive Manufacturing**
---**Volker Carl**, Carl Messtechnik, Dinslaken, Germany

1:30 PM

Summary of NDE of Additive Manufacturing Efforts in NASA

---Jess M. Waller, Kenneth L. Hodges, Karen H. B. Taminger, Bradford H. Parker, and **Regor L. Saulsberry**, NASA White Sands Test Facility, NASA Goddard Space Flight Center, Las Cruces, NM 88004-0020

---One of the major obstacles slowing the acceptance and use of AM parts in NASA applications is the lack of a broadly accepted materials and process quality systems; and more specifically, the lack of adequate nondestructive evaluation (NDE) processes integrated into AM. Matching voluntary consensus standards are also needed to ensure AM material process control and traceability, process consistency, part accuracy, surface finish control, and standardization of finished part characterization using destructive and nondestructive means. As for nondestructive characterization, procedures are needed to interrogate features that are unique to AM parts, such as fine scale porosity, complex part geometry, and intricate internal features. The nondestructive procedures developed also need to be tailored to meet materials, design and test requirements encountered throughout the AM part life cycle; whether during process optimization, real-time iterative process control, finished part qualification and (re-)certification, or in-situ health monitoring. Restated, individualized process/product-specific inspections are needed to satisfy general QA requirements for AM parts. To date, little if any work has been done in regards to qualification and certification of NASA flight hardware using NDE. Both metal and plastic AM parts are covered, and the approach NASA is taking to apply NDE to additive manufacturing is summarized. A comprehensive State-of-the-Discipline report on NDE of Additive Manufacturing for NASA Applications has also been prepared is in the NASA review process. This report provides a more in-depth discussion of the work summarized here.

2:10 PM

Near-Infrared Machine Vision and NDE for Additive Manufacturing
---**Eric Burke** and Joseph Zalameda, NASA Langley Research Center, NASA LaRC B1230, Rm. 151, MS231, Hampton, VA 23681-2199

---Several advancements in the area of feedback and control using near-infrared imaging and machine vision techniques are being used to improve the quality of Electron Beam Free Form Fabrication (EBF3). Advancements include temperature calibration of commercial near infrared cameras for measurement and characterization of weld pool characteristics. Additional advancements include multiple cameras, real-time tracking and feedback algorithms to improve weld shape consistency. Implementations of these systems have improved the consistency of stainless steel straight wall samples. Use of calibrated near-infrared cameras has been shown to enable detection of defects in parts during fabrication. Several advancements in the area of feedback and control using near-infrared imaging and machine vision techniques are being used to improve the quality of Electron Beam Free Form Fabrication (EBF3). Advancements include techniques for temperature calibration of commercial near infrared cameras for measurement and characterization of weld pool characteristics. Temperature calibrations are specific to each individual camera and temperature range of the material being inspected. This is achieved using black body calibrations in the temperature ranges of the solidification ranges of the material under investigation. Further advancements include multiple cameras, real-time tracking and feedback algorithms to improve weld shape consistency. Multiple cameras allow for simultaneous top and side view characterizations of the weld in real-time. Real-time shape and tracking algorithms allow implementations of power feedback to control the temperature of the weld pool faster than what is humanly possible. Various parameters of temperature, shape and cooling rate can be used to create metrics that are used for feedback and control in real-time. Implementations of these systems have improved the consistency of stainless steel straight wall samples. Use of calibrated near-infrared cameras has been shown to enable detection of defects in parts during fabrication.

2:30 PM

A Study of Internal Structure in Components Made by Additive Manufacturing Process Using 3D X-Ray Tomography

---Raguvarun K[1], Krishnan Balasubramaniam[1], and **Prabhu Rajagopal**[1], [1]IIT Madras, Centre for Nondestructive Evaluation, Chennai 600036, T.N., India; Suresh Palanisamy[2,4] and Romesh Nagarajah[2], [2]Swinburne University of Technology, Faculty of Engineering, Science and Technology, Hawthorn, VIC 3122, Australia; Nicholas Hoye[3,4] and Dominic Curiri[3,4], [3]University of Wollongong, Faculty of Engineering, NSW 2522, Australia; [4]Defence Materials Technology Centre, Hawthorn, VIC 3122, Australia

---Additive manufacturing methods are gaining increasing popularity for rapidly and efficiently manufacturing parts and components in the industrial context, as well as for domestic applications. However, except when used for prototyping or rapid visualization of components, industries are concerned with the load carrying capacity and strength achievable by additive methods. In this paper, the wire-arc additive manufacturing (AM) process based on gas tungsten arc welding (GTAW) has been examined for the internal structure and constitution of components generated by the process. High-resolution 3D X-ray tomography is used to gain cut-views through wedge-shaped parts created using this GTAW additive manufacturing process with Titanium alloy materials. In this work, two different control conditions for the GTAW process are considered. The studies reveal clusters of porosities, located in periodic spatial intervals along the sample cross-section. Such internal defects can have a detrimental effect on the strength of the resulting AM components, as shown in destructive testing studies. Closer examination of this phenomenon shows that defect clusters are preferentially located at GTAW traversal path intervals. These results highlight the strong need for enhanced control of process parameters in ensuring components with minimal defects and higher strength.

2:50 PM

Online Layer-Wise Ultrasonic Non-Destructive Certification of an Ultrasonic Additive Manufacturing System for Closed Loop Control Applications

---**Venkata Karthik Nadimpalli**, John S. D. Jangam, Deepankar Pal, and Brent E. Stucker, Department of Industrial Engineering, J. B. Speed School of Engineering, University of Louisville, Louisville, KY 40217; Jeong K. Na, Aerospace Group, Wyle Research Laboratories, 2700 Indian Ripple Road, Dayton, OH

---Layer by layer manufacturing offers a unique opportunity for online NDT since it is probable that defects formed in one layer might be corrected in subsequent layers by suitable selection of parameters. An ultrasonic NDT setup has been integrated into an existing Ultrasonic Additive Manufacturing (UAM) machine along with the ability to change process parameters on the fly. Ultrasonic Consolidation is a layer based solid state fusion process which bonds one layer of foil (150μm) on top of a base by imparting vibrational energy at 20,000 Hz frequency leading to solid state bonding. This leads to a very fine grained subsurface micro-structure which has good strength, and is free from common metal joining problems associated with melting such as solidification cracking and gas entrapment. But the drawback is that it poses problems such as delamination when the bonding parameters are not optimal. Solid state fusion processes like UAM hence have great potential if we are able to ensure good bonding. UAM process parameters are geometry and layer number dependent owing to the fact that energy is imparted via vibration. When the process parameters are not optimal at a given layer, we observe that delamination and cracks start developing and the bond strength is not ideal. To measure the combined effect of these phenomena, it is observed that the velocity of longitudinal and shear ultrasonic waves is an indicator of the overall quality of build up to the current layer. Surface acoustic waves (SAW) using Inter Digitized Transducers (IDT's) give us an indication of the just bonded layers. While it was observed that SAW's, Longitudinal and Shear wave measurements give qualitative estimates of bonding, it is necessary to correlate the ultrasonic feedback to mechanical properties and the optical micro-graph's. We propose to analyze and compare the bond strength and presence of delamination over a large factorial set of experiments while collecting ultrasonic feedback every layer. The database created will be analyzed to generate quantitative outputs that can be calculated from ultrasonic feedback. A control loop will be used to demonstrate the effectiveness of using an ultrasonic feedback for closed loop control of the UAM system.

3:30 PM

Overview of Additive Manufacturing Activities at MTU Aero Engines
---**Joachim Bamberg**, Karl-Heinz Dusel, and Wilhelm Satzger, MTU Aero Engines, Manufacturing Technology, Munich, Germany

---Additive Manufacturing (AM) is a promising technology to produce parts easily and effectively, just using metallic powder or wire as starting material and a sophisticated melting process. In contrast to milling or turning technologies complex shaped and hollow parts can be built up in one step. That reduces the production costs and allows the implementation of complete new 3D designs. Therefore AM is also of great interest for aerospace and aero engine industry. MTU Aero Engines has focused its AM activities to the selective laser melting technique (SLM). This technique uses metallic powder and a laser for melting and solidifying the part geometry layer by layer. It is shown which lead parts MTU has selected for AM and how the first production line was established. A special focus is set on the quality assurance of the selective laser melting process. In addition to standard non-destructive inspection techniques, some new kinds of online monitoring tools were developed and integrated into the SLM machines. The basics of these techniques are presented. An outlook to future activities of AM and quality assurance concludes this talk.

3:50 PM

Process Monitoring of Additive Manufacturing by Using Optical Tomography
---**Guenter Zenzinger**, Joachim Bamberg, T. Hess, and Alexander Ladewig, MTU Aero Engines, Manufacturing Technology, Munich, Germany

---Parts fabricated by means of additive manufacturing are usually of complex shape and owing to the fabrication procedure by using selective laser melting (SLM), potential defects and inaccuracies are often very small in lateral size. Therefore, an adequate quality inspection of such parts is rather challenging, while non-destructive-techniques (NDT) are difficult to realize, but considerable efforts are necessary in order to ensure the quality of SLM-parts especially used for aerospace components. Thus, MTU Aero Engines is currently focusing on the development of an Online Process Control system which monitors and documents the complete welding process during the SLM fabrication procedure. A high-resolution camera system is used to obtain images, from which tomographic data for a 3dim analysis of SLM-parts are processed. From the analysis, structural irregularities and structural disorder resulting from any possible erroneous melting process become visible and may be allocated anywhere within the 3dim structure. Results of our optical tomography (OT) method as obtained on real defects are presented.

4:10 PM

Monitoring System for the Quality Assessment in Additive Manufacturing
---**Volker Carl**, Carl Messtechnik, Dinslaken, Germany

---Additive Manufacturing (AM) refers to a process by which a set of digital data - representing a certain complex 3dim design - is used to grow the respective 3dim real structure equal to the corresponding design. For the powder-based EOS manufacturing process a variety of plastic and metal materials can be used. Thereby, AM is in many aspects a very powerful tool as it can help to overcome particular limitations in conventional manufacturing. AM enables more freedom of design, complex, hollow and/or lightweight structures as well as product individualization and functional integration. As such it is a promising approach with respect to the future design and manufacturing of complex 3dim structures. On the other hand, it certainly calls for new methods and standards in view of quality assessment. In particular, when utilizing AM for the design of complex parts used in aviation and aerospace technologies, appropriate monitoring systems are mandatory. In this respect, recently, sustainable progress has been accomplished by joining the common efforts and concerns of a manufacturer Additive Manufacturing systems and respective materials (EOS), along with those of an operator of such systems (MTU Aero Engines) and experienced application engineers (Carl Metrology), using decent know how in the field of optical and infrared methods regarding non-destructive-examination (NDE). The newly developed technology is best described by a high-resolution layer by layer inspection technique, which allows for a 3D tomography-analysis of the complex part at any time during the manufacturing process. Thereby, inspection costs are kept rather low by using smart image-processing methods as well as CMOS sensors instead of infrared detectors. Moreover, results from conventional physical metallurgy may easily be correlated with the predictive results of the monitoring system which not only allows for improvements of the AM monitoring system, but finally leads to an optimization of the quality and insurance of material security of the complex structure being manufactured. Both, our poster and our oral presentation will explain the data flow between the above mentioned parties involved. A suitable monitoring system for Additive Manufacturing will be introduced, along with a presentation of the respective high resolution data acquisition, as well as the image processing and the data analysis allowing for a precise control of the 3dim growth-process.

Session 6

SESSION 6
ELECTROMAGNETICS EDDY CURRENT
Norio Nakagawa and H. A. Sabbagh, Co-Chairpersons
Salmon-Snake

1:30 PM **Novel Coil Designs for Eddy Current Sensors in Inspection of Multilayer Riveted Structures**
---**Gerges Dib**, Guang Yang, Lalita Udpa, and Satish S. Udpa, Nondestructive Evaluation Laboratory, Michigan State University, East Lansing, MI 48824; Antonello Tamburrino, Department of Electrical and Information Engineering, University of Cassino and Lazio Meridionale, Cassino 03043, Italy

1:50 PM **Role of Interface Conditions in Low Frequency Electromagnetic Testing of Multilayer Structures**
---**Aaron J. Cherry[2]**, Matthew R. Cherry[1], John C. Aldrin[3], Eric Lindgren[1], Harold A. Sabbagh[4], Thomas Boehnlein[5], Ryan Mooers[1], Jeremy Knopp[1]; [1]Structural Materials Division, AFRL, WPAFB, OH 45433; [2]Southwestern Ohio Council for Higher Education, Dayton, OH 45420; [3]Computational Tools, Gurnee, IL 60031; [4]Victor Technologies, LLC, Bloomington, IN 47401; [5]University of Dayton Research Institution, Dayton, OH, 45469

2:10 PM **Experimental Test of a Nonlinear Eddy Current NDE Model in Weak Nonlinearity**
---**Norio Nakagawa**, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

2:30 PM **Realistic Split D Differential Probe Model Validation**
---**Ryan D. Mooers[1]** and John C. Aldrin[2], [1]Air Force Research Labs, Materials State Awareness and Supportability Branch (AFRL/RXCA), Wright Patterson AFB, OH 45433; [2]Computational Tools, Gurnee IL 60031

2:50 PM **Modeling the Effects of Core/Coil Size and Defect Length on Eddy Current Response**
---**Ryan D. Mooers[1]** and John C. Aldrin[2], [1]Air Force Research Labs, Materials State Awareness and Supportability Branch (AFRL/RXCA), Wright Patterson AFB, OH 45433; [2]Computational Tools, Gurnee IL 60031

3:10 PM ***Break***

3:30 PM **Optimization of Coil Design for Near Uniform Interrogating Field Generation**
---**Z. Su[1, a)]**, V. Rega[2], A. Tamburrino[1, 2], L.Udpa[1], S.S. Udpa[1], [1]Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824; [2]University of Cassino and Lazio Meridionale, Department of Electrical and Information Engineering, Cassino (FR), 03043 Italy

3:50 PM **High-Frequency Eddy Current Based Impedance Spectroscopy for Characterization of the Percolation Process of Wet Conductive Coatings**
---**Iryna Patsora**, Technical University of Dresden, fur Aufbau- und Verbindungstechnik, Barkhausenbau, Helmholzstr., 1806069 Dresden, Germany; Susanne Hillmann, Henning HeuerFraunhofer IKTS-MD Dresden; Bryan C. Foos, Juan G. Calzada, and Adam T. Cooney, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

4:10 PM **Dynamic ECA Lift-Off Compensation**
---Benoit Lepage and **Charles Brillon**, Olympus NDT, Solutions and Technology Development, Quebec, Qc G1P 4S9, Canada

4:30 PM **Eddy Current Sensor for In-Situ Monitoring of Swelling of Li-Ion Prismatic Cells**
---**Yuri A. Plotnikov**, Jason Karp, Aaron Knobloch, and David Lin, GE Global Research, 1 Research Circle, KW-D253A, Niskayuna, NY 12309

1:30 PM

Novel Coil Designs for Eddy Current Sensors in Inspection of Multilayer Riveted Structures

---**Gerges Dib**, Guang Yang, Lalita Udpa, and Satish S. Udpa, Nondestructive Evaluation Laboratory, Michigan State University, East Lansing, MI 48824; Antonello Tamburrino, Department of Electrical and Information Engineering, University of Cassino and Lazio Meridionale, Cassino 03043, Italy

---The challenge in detecting crack under fastener heads (CUF) in a multi-layered aircraft structure poses the need for advanced NDE technology. Our previous work has presented the feasibility of eddy current (EC) technology using giant magnetoresistive (GMR) sensors in detecting 2nd and 3rd layer hidden cracks in layered aircraft components. An EC-GMR inspection system has been developed to directly measure the normal component of magnetic flux density associated with eddy currents induced inside the specimen. In the current testing system, electromagnetic NDE methods using low frequency EC and transient EC excitation in combination with GMR sensors have enhanced the detection of deep buried flaws. However, a major limitation of current sensor system is in detecting cracks that are parallel to the direction of induced currents. This paper presents a new design using orthogonal excitation coils for generating a rotating uniform current, which provides uniform sensitivity to cracks emanating in all orientations around fastener sites. The design and inspection using the orthogonal coil probe and GMR sensor is presented using a simulation model. Several candidate designs for the orthogonal coil configuration will be presented using the simulation model. The detection of cracks in all radial directions around aluminum and steel fasteners are validated numerically and experimentally.---This material is based upon work supported by the AFRL under Contract FA8650-10-D-5806-5210, Task Order 028.

1:50 PM

Role of Interface Conditions in Low Frequency Electromagnetic Testing of Multilayer Structures

---**Aaron J. Cherry**[2], Matthew R. Cherry[1], John C. Aldrin[3], Eric Lindgren[1], Harold A. Sabbagh[4], Thomas Boehnlein[5], Ryan Mooers[1], Jeremy Knopp[1]; [1]Structural Materials Division, AFRL, WPAFB, OH 45433; [2]Southwestern Ohio Council for Higher Education, Dayton, OH 45420; [3]Computational Tools, Gurnee, IL 60031; [4]Victor Technologies, LLC, Bloomington, IN 47401; [5]University of Dayton Research Institution, Dayton, OH, 45469

---When developing simulations of NDE testing methods it is imperative to use an accurate physical representation. Many inaccuracies in simulations can be traced to faulty or incomplete assumptions made for specific problem geometries, parameter constraints, or boundary conditions. An example of this is the assumed eddy current flaw response in layered media. A critical assumption often made is that when the plates are in contact, they are in electrical contact and behave as a single conductor. The purpose of this study is to dissect this assumption and propose alternate representations of the problem. A series of experiments were conducted alongside numerical models to provide evidence of the inadequacy of the assumption. Simulations were also used to predict the effects of varying interface conditions on eddy current signals due to surface cracks in sub-layer metals.

2:10 PM

Experimental Test of a Nonlinear Eddy Current NDE Model in Weak Nonlinearity
---**Norio Nakagawa**, Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011

---A theory of nonlinear eddy current (NLEC) NDE response was presented by the author last year. The theoretical model is applicable to describe EC NDE measurements involving a ferromagnetic material, treating the nonlinearity at the lowest nontrivial order. The ferrous material in question can be a ferrite core in the typical EC probe to be modeled, or a part made of alloy steel. This paper presents the results of an experimental study that tests the consistency of the model against experimental data. Coils wound around ferrite rods, made of the ferrite material #33, are prepared for the test. Laboratory grade instrumentation has been assembled to drive the coils, and then to detect response signals. The data and their analyses are presented, showing that 1) the impedance signal indeed shows nonlinear behaviors, i.e. the coil impedance around the ferrite core depends, although weakly, on the drive current, that 2) the coil impedance varies linearly as a function of the drive current, i.e. we manage to keep the drive level at the lowest order of nonlinearity (Rayleigh regime), and that 3) the linear and nonlinear parts of the coil impedance are consistent with the linear and nonlinear theory predictions, respectively. From the comparison between the theory and experiment, we determine the two basic material parameters, i.e. the initial permeability and the Rayleigh nonlinearity constant, for the #33 ferrite material. Finally, we present a consideration toward an independent method of determining the two parameters, for ultimate model validation.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

2:30 PM

Realistic Split D Differential Probe Model Validation

---Ryan D. Mooers[1] and John C. Aldrin[2], [1]Air Force Research Labs, Materials State Awareness and Supportability Branch (AFRL/RXCA), Wright Patterson AFB, OH 45433; [2]Computational Tools, Gurnee IL 60031

---In split D model validation problems, the probe is usually modeled with perfect symmetry and with all similar components having the same dimensions [1, 2]. When it comes to trying to match an actual coil these assumptions lead to discrepancies in the results. To truly validate a model based on a commercial coil the variations present between the various components must be included. This could include small difference in the size of the coils and ferrite core if present. It could also mean incorporating any angular deviations the components may have from one another. These variations lead to what is known as imbalance in the probe, in which one of the coils produces a slightly different signal to the other. This leads to an asymmetric look to the probe response. This paper details the results of a validation exercise based on a commercial split D differential probe that is known to be unbalanced, it will also give a more details description of the meaning of unbalance. Various models of the probe will be created to show how the variations between components affect the probe response. The changes will be made is a systematic way to show how various changes could then be combined to more accurately model the probe. Ultimately, this will show how capable state of the art eddy current modeling software is at modeling these realistic probes. The details of the experimental data collection and data analysis will also be provided. Results from all the various sub models will be compared and some general conclusions about the success of the modeling will be presented.

References:

1. R. D. Mooers, J. S. Knopp and M. P. Blodgett, "Model Based Studies of the Split D Differential Eddy Current Probe," in *Review of Progress in QNDE*, edited by D. O. Thompson and D. E. Chimenti, (AIP, 2012), 1430 pp. 373-380.
2. R. D. Mooers, J. S. Knopp, J. C. Aldrin, and S. Sathish, "Split D DifferentiValidation Using an Impedance Analyzer," in Review of Progress in QNDE, Edited by D. O. Thompson and D. E. Chimenti, (AIP, 2013) 1581, pp. 1511-1518.

2:50 PM

Modeling the Effects of Core/Coil Size and Defect Length on Eddy Current Response

---**Ryan D. Mooers**[1] and John C. Aldrin[2], [1]Air Force Research Labs, Materials State Awareness and Supportability Branch (AFRL/RXCA), Wright Patterson AFB, OH 45433; [2]Computational Tools, Gurnee IL 60031

---In past validation efforts involving Split D Differential probes [1, 2], there are areas where the agreement between model and experiment has been poor compared to the remainder of the scan. In most cases, this discrepancy arises between the major peaks when the probe is scanned along the length of the defect. This paper presents an effort to determine the cause of this discrepancy. These discrepancies could be caused by difference between the modeled and actual probe or due to an underlying issue with the numerical solution employed by the software. Two commercial split D differential eddy current coils are used in this study each of them having different sized D cores and coil. Three different electric discharge machining (EDM) notches, of varying lengths, are used in the study with scans being run both along the length and across the width of the notches. The combination of different lengths and different coil diameters will be used to determine if a correlation exists between the component values. As opposed to past efforts, the various components of the two probe models will not simulate a perfect probe. Contrarily, these components will mimic the variations seen in hand built commercial coils. It is believed that the majority of the discrepancy seen could be corrected from this change. A complete description of the modeled probes, the experimental procedure, and all data analysis will be presented. Comparisons of the various notch lengths and coil diameters will be made and conclusions about the cause for the previously stated discrepancies will be given.

References:

1. R. D. Mooers, J. S. Knopp and M. P. Blodgett, “Model Based Studies of the Split D Differential Eddy Current Probe,” in *Review of Progress in QNDE*, edited by D. O. Thompson and D. E. Chimenti, (AIP, 2012), 1430 pp. 373-380.
2. R. D. Mooers, J. S. Knopp, J. C. Aldrin, and S. Sathish, “Split D DifferentiValidation Using an Impedance Analyzer,” in *Review of Progress in QNDE*, Edited by D. O. Thompson and D. E. Chimenti, (AIP, 2013) 1581, pp. 1511-1518.

3:30 PM

Optimization of Coil Design for Near Uniform Interrogating Field Generation
---**Z. Su**[1, a)], V. Rega[2], A. Tamburrino[1, 2], L.Udpa[1], S.S. Udpa[1], [1]Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824; [2]University of Cassino and Lazio Meridionale, Department of Electrical and Information Engineering, Cassino (FR), 03043 Italy

---The detection of a crack under fastener heads (CUF) in a multi-layered aircraft structure remains a challenge in NDE. Our previous work has presented the feasibility of using a linear eddy current (EC) coil with giant magnetoresistive (GMR) sensors on the axis of symmetry for detecting 2nd and 3rd layer hidden cracks in layered aircraft components. An EC-GMR inspection system has been developed to directly measure the normal component of magnetic flux density associated with eddy currents induced inside the specimen. In the EC-GMR system, the signal received from sensors is greatly influenced by the interrogating field. Small deviations of sensor positions from the axis of symmetry can result in false measurements. In an ideal case, excitation current generates an interrogating field which is uniform and tangential with zero vertical field component at the sensor. Only cracks and fasteners generate a vertical component that is measured by the sensor. This paper describes a detailed parametric study, using a finite element model and uses the results in a multi-objective as well as multi-parameter optimization problem for coil design. The parameters considered are related to coil geometry, including coil size, width of current strips, current distribution, etc. Experimental validation of the design will also be presented.---This material is based upon work supported by the AFRL under Contract FA8650-10-D-5806-5210, Task Order 028.

3:50 PM

High-Frequency Eddy Current Based Impedance Spectroscopy for Characterization of the Percolation Process of Wet Conductive Coatings

---**Iryna Patsora**, Technical University of Dresden, fur Aufbau- und Verbindungstechnik, Barkhausenbau, Helmholzstr., 1806069 Dresden, Germany; Susanne Hillmann, Henning HeuerFraunhofer IKTS-MD Dresden; Bryan C. Foos, Juan G. Calzada, and Adam T. Cooney, Air Force Research Laboratory

---Coatings based on wet particles containing pastes are currently used in many industries, such as automotive, aircraft and/or wind-power plants, to protect carbon-fiber reinforced plastic against damages caused by electrical effects, such as a lightning strike. In order to understand and control the percolation behavior during the drying, a non-contact Eddy Current based impedance spectroscopy can be used. This technique can be applied in the wet state of the coating and it works non-destructively. Percolation behaviors of the wet conductive coatings are strongly affected by the type of particles used as a filling and the thickness of the coating. Experimental results of Eddy Current measurements for wet conductive coatings based on different conductive particles are discussed. Based on High-Frequency Eddy Current measurements, a prognosis of the coating parameters after final curing during the wet state becomes conceivable. This offers a wide opportunity for process control and repairs, for example.

4:10 PM

Dynamic ECA Lift-Off Compensation
---Benoit Lepage and **Charles Brillon**, Olympus NDT, Solutions and Technology Development, Quebec, Qc G1P 4S9, Canada

---Good control on lift-off is crucial in Eddy Current testing as the signal amplitude is directly affected by lift-off changes, potentially leading to reduced detection performance and/or to false positives. This is especially true in automated inspections and/or with Eddy Current Array (ECA) technology, where lift-off cannot be mechanically compensated for at each coil position. In this work we report on a novel method for compensating sensitivity variations induced by varying lift-off for an ECA probe. This method makes use of a single ECA probe operated in two different ways: One is to create a set of detection channels and the other is to create a set of lift-off measurement channels. Since a simple relationship exists between the two measurements, an improved calibration process can be used which combines the calibration of both detection and lift-off measurement channels on a simple calibration block exhibiting a reference defect, thus eliminating the need for a pre-defined lift-off condition. In this work, we will show results obtained on weld caps where lift-off condition varies significantly over the scanning area.

4:30 PM

Eddy Current Sensor for In-Situ Monitoring of Swelling of Li-Ion Prismatic Cells
---**Yuri A. Plotnikov**, Jason Karp, Aaron Knobloch, and David Lin, GE Global Research, 1 Research Circle, KW-D253A, Niskayuna, NY 12309

---In-situ monitoring an on-board rechargeable battery in hybrid cars can be used to ensure a long operating life of the battery and safe operation of the vehicle. Intercalations of ions in the electrode material during charge and discharge of a Lithium Ion battery cause periodic stress and strain of the electrode materials that can ultimately lead to fatigue resulting in capacity loss and potential battery failure. Currently this process is not monitored directly on the cells. This work is focused on development technologies that would quantify battery swelling and provide in-situ monitoring for onboard vehicle applications. Several rounds of tests have been performed to spatially characterize cell expansion of a 5 Ah cell with a nickel/manganese/cobalt-oxide cathode (Sanyo, Japan) used by Ford in their Fusion HEV battery pack. A collaborative team of researchers from GE and the University of Michigan has characterized the free expansion of these cells to be in the range of 100-125 microns (1% of total cell thickness) at the center point of the cell. GE proposed to use a thin eddy current (EC) coil to monitor these expansions on the cells while inside the package. The photolithography manufacturing process previously developed for EC arrays for detecting cracks in aircraft engine components was used to build test coils for gap monitoring. These sensors are thin enough to be placed safely between neighboring cells and capable of monitoring small variations in the gap between the cells. Preliminary investigations showed that these coils can be less than 100 micron thick and have sufficient sensitivity in a range from 0 to 2 mm. Laboratory tests revealed good correlation between EC and optical gap measurements in the desired range. Further technology development could lead to establishing a sensor network for a low cost solution for the in-situ monitoring of cell swelling during battery operation.

TUESDAY

TUESDAY, JULY 22, 2014

	Session 7 **Phased Arrays I** ***Peregrines***	**Session 8** **Civil Structures and Concrete** ***Pines-Willows***	**Session 9** **Radiography I** ***Cottonwoods-Firs***	**Session 10** **Noncontact and Optical** ***Salmon-Snake***
8:30 AM				
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10:10	COFFEE BREAK			
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12:10 PM	LUNCH			
Session 11 – POSTERS – 1:30 – 3:10 PM – *Hawk*				
	Session 12 **Phased Arrays II** ***Peregrines***	**Session 13** **Terahertz NDE** ***Salmon-Snake***	**Session 14** **Nuclear Reactors I** ***Cottonwoods-Firs***	**Session 15** **Additive Manufacturing II** ***Pines-Willows***
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Session 7

SESSION 7
PHASED ARRAYS I
Paul Wilcox, Chairperson
Peregrines

8:30 AM **A New Software Toolbox for Evaluating Advanced Ultrasonic Array Imaging Techniques**
---**Timothy Lardner**, Jerzy Dziewierz, Ailidh McGilp, Arjun T. Kadumberi, Rui Gongzhang, Bo Xiao, and Anthony Gachagan, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, 204 George Street, Glasgow, G1 1XW, United Kingdom

8:50 AM **Optimum Array Element Pitch for NDE Applications**
---**Paul D. Wilcox**, Faculty of Engineering, University of Bristol, Bristol, United Kingdom

9:10 AM **A Comparison of 1D and 1.5D Ultrasonic Arrays for Imaging Through High Curvature Surfaces**
---**Thomas S. Barber** and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, University Walk, Bristol BS8 1TR, United Kingdom; Andrew D. Nixon, BAE Systems Submarines, Materials Technology, Barrow-in-Furness, Cumbria, United Kingdom

9:30 AM **Comparison of Ultrasonic Image Features with Echodynamic Curves for Defect Classification and Characterization**
---**Jie Zhang** and Bruce W. Drinkwater, Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, United Kingdom; Sam Wedge and Allan Rogerson, NDT, AMEC, Clean Energy – Europe, Walton House, Birchwood Park, Warrington, WA3 6GA, UK

9:50 AM **Optimization of Ultrasonic Array Inspections Using an Efficient Hybrid Model and Real Crack Shapes**
---**Maria V. Felice**, Alexander Velichko, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol BS8 1TR, United Kingdom; Tim J. Barden and Tony K. Dunhill, Rolls-Royce plc., NDE Laboratory, Bristol BS8 1TR, United Kingdom

10:10 AM ***Break***

10:30 AM **Ultrasonic Scattering Matrix Extraction for Near-Surface Defects**
---Peng Yu, **Jie Zhang** and Bruce W. Drinkwater, Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, United Kingdom; Peng Yu and Tie Gang, State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China

10:50 AM **Depth Measurement of Small Surface-Breaking Cracks Using the Half-Skip Total Focusing Method**
---**Maria V. Felice**, Alexander Velichko, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol BS8 1TR, United Kingdom; Christopher J. Lane, Rolls-Royce plc., NDE Laboratory, Derby, United Kingdom

11:10 AM **Resolution Enhancement of Subharmonic Phased Array Using MUSIC Algorithm**
---**Choon-Su Park**, Jun-Woo Kim, Seunghyun Cho, and Dae-Cheol Seo, Korea Research Institute of Standards and Science (KRISS), Division of Metrology for Quality of Life, 267 Gajeong-ro, Yuseong-gu, Daejeon, 305-340

11:30 AM **Development of Confocal Subharmonic Phased Array for Crack Evaluation for Closed Crack Imaging and Analyses of Nonlinear Scattering Behaviors**
---**Yoshikazu Ohara**, Azusa Sugawara, Kentaro Jinno, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

11:50 AM **Full-Matrix Capture on Customizable Ultrasonic Phased Array Instrument**
---**Gavin Dao**, Advanced OEM Solutions, 8044 Montgomery Road #700, Cincinnati, OH 45236; Matt Gruber, The Phased Array Company, 9277 Centre Pointe Dr. #350, West Chester, OH 45069

12:10 PM ***Lunch***

8:30 AM

A New Software Toolbox for Evaluating Advanced Ultrasonic Array Imaging Techniques

---**Timothy Lardner**, Jerzy Dziewierz, Ailidh McGilp, Arjun T. Kadumberi, Rui Gongzhang, Bo Xiao, and Anthony Gachagan, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, 204 George Street, Glasgow, G1 1XW, United Kingdom

---Technological developments in the field of ultrasonic array transducer technology and associated imaging algorithms are continually advancing and finding new applications. Moreover, there is an industrial drive towards real-time implementation. This paper presents a fast and efficient software platform based on a plug-in strategy. The approach is compatible with a number of phased array instruments and is advantageous for both the design of inspection techniques, including application of sparse 2D phased arrays, and to compare emerging imaging techniques with conventional beam forming approaches. Importantly, the platform is compatible with ultrasonic inspection within an industrial setting. The foundation of the software was created in LabVIEW and uses DLLs to extend functionality. These DLLs include device drivers for phased array implementation, allowing real-time acquisition of ultrasonic data, and wrappers for CUDA, allowing advanced GPU-based imaging techniques to be easily included in the software. An open-source volume ray-casting program has been modified to allow its high quality 3D imaging functionality to be exploited. Using these ‘building-blocks’, a fully-functional phased-array inspection software toolkit has been created that allows quick and easy comparisons to be made between different imaging algorithms and a range of phased array controllers. The software platform performance will be demonstrated by comparing imaging performance of three signal processing approaches - Total Focusing Method, Phase Coherence Factor, Spatially Averaged Sub-Aperture Correlation Imaging – on both highly-scattering and conventional materials. Importantly, the high efficiency of the platform is confirmed by the real-time and interactive TFM output for a 64-element 2D sparse array inspecting an industrially relevant sample component, through a water layer.

8:50 AM

Optimum Array Element Pitch for NDE Applications
---**Paul D. Wilcox**, Faculty of Engineering, University of Bristol, Bristol, United Kingdom

---Despite the widespread use of ultrasonic arrays in NDE applications, there is a lack of quantitative understanding about the effect of inter-element pitch. The number of elements in an array is usually limited by the available channels of the array controller device and/or connectivity, thus the pitch is important because it determines the maximum spatial aperture for an array with limited elements. The conservative “half-wavelength” pitch rule is often quoted and guarantees no grating lobe artefacts, but is rarely adhered to. Despite this, NDE practitioners still routinely use spatially under-sampled arrays and obtain perfectly acceptable images. This paper explains why this is, how knowledge of the imaging requirements may be used to obtain the optimum element pitch and how signal-processing may be used to suppress imaging artefacts due to spatial under-sampling. First, an analytical model of monochromatic, far-field array behavior is developed to qualitatively illustrate the relationship between element pitch and maximum steering angle. This model enables prediction of peak grating lobe amplitude in an image, and the relationship between image structural noise (due to material microstructure) and element pitch. However, this model remains overly conservative as a quantitative tool for determining array inter-element pitch, due to the assumption of monochromatic, far-field operation. Virtually all NDE applications involve broadband pulse excitation and many also use focusing, both of which lead to a smearing out of grating lobe artefacts. To obtain a useful quantitative tool for array design, a more complete numerical model is developed and validated experimentally. The extension of findings from this model to both 2D arrays and immersion inspections is discussed.

9:10 AM

A Comparison of 1D and 1.5D Ultrasonic Arrays for Imaging Through High Curvature Surfaces

---**Thomas S. Barber** and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, University Walk, Bristol BS8 1TR, United Kingdom; Andrew D. Nixon, BAE Systems Submarines, Materials Technology, Barrow-in-Furness, Cumbria, United Kingdom

---The NDE of high curvature industrial components is a common inspection problem over a variety of industrial sectors particularly in the form of pipe weld inspection. Conventionally, accurate and reliable volumetric inspection of such welds can only be achieved through radiographic techniques which are often highly impractical and time consuming particularly in a confined working environment. This article examines the inspection capability of Full Matrix Capture, the Total Focusing Method (TFM) and a 1.5D ultrasonic array when applied to the immersion inspection of 30-60mm diameter pipe welds. A 3D simulation of the inspection problem is described based on a linear systems model and is used to inform the development of a TFM algorithm capable of partial 3D auto-focusing through a curved pipe surface using a 1.5D array. The algorithm is experimentally demonstrated and imaging performance compared to 2D autofocusing using a 1D array.

9:30 AM

Comparison of Ultrasonic Image Features with Echodynamic Curves for Defect Classification and Characterization

---**Jie Zhang** and Bruce W. Drinkwater, Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, UK; Sam Wedge and Allan Rogerson, NDT, AMEC, Clean Energy – Europe, Walton House, Birchwood Park, Warrington, WA3 6GA, United Kingdom

---Ultrasonic array imaging and multi-probe pulse echo inspection are two common ultrasonic techniques used for defect detection, classification and characterization in non-destructive evaluation. Compared to multi-probe pulse echo inspection, ultrasonic array imaging offers some advantages such as higher resolution images and the requirement to obtain fewer measurements. However, it is also limited by a lack of industry-approved inspection procedures and standards. In this paper, several artificial planar and volumetric weld defects of different orientations and locations embedded in 60 mm thick welded ferritic test specimens were measured using both ultrasonic arrays and multiple signal crystal probes. The resultant TFM images and echodynamic curves for each defect were compared and the results demonstrate the correlations between TFM image features and echodynamic curve characteristics. Combining the analysis of multi-probe pulse echo inspection data and ultrasonic array images offers better classification and characterization of defects. These findings benefit the further development of industrial ultrasonic array inspection procedures and encourage the uptake of TFM technology within industry.

9:50 AM

Optimization of Ultrasonic Array Inspections Using an Efficient Hybrid Model and Real Crack Shapes

---**Maria V. Felice**, Alexander Velichko, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol BS8 1TR, United Kingdom; Tim J. Barden and Tony K. Dunhill, Rolls-Royce plc., NDE Laboratory, Bristol BS8 1TR, United Kingdom

---Models which simulate the interaction of ultrasound with cracks can be used to optimize ultrasonic array inspections, but this approach can be time-consuming. To overcome this issue, in this paper, an efficient hybrid model is implemented. The model incorporates a finite element method that requires only a single layer of elements around the crack shape. Real crack shapes are obtained from X-ray Computed Tomography images of cracked parts and these shapes are inputted into the hybrid model. This methodology is used to design an 'in situ' aerospace engine inspection for stress corrosion cracking. The hybrid model is run for a variety of array inspections and the optimum inspection for a set of crack shapes is determined. Physical array parameters, such as element pitch, are varied as well as the position of the array with respect to the crack and the array imaging method employed. Constraints are included, in particular the maximum array size that can be fitted into the engine. The use of the efficient model enables a large variety of inspections to be considered in a reasonable amount of time. The use of the real crack shapes enables a more reliable optimum inspection to be determined.

10:30 AM

Ultrasonic Scattering Matrix Extraction for Near-Surface Defects
---Peng Yu, **Jie Zhang** and Bruce W. Drinkwater, Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, United Kingdom; Peng Yu and Tie Gang, State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China

---Ultrasonic arrays have been widely used and developed for defect detection and characterization over the last 10 years. In this paper we address the question of how to inspect and characterize near-surface defects that are small with respect to the wavelength. The challenge is to overcome the poor signal to noise (due to low scattered amplitude from small defects) and the proximity of these scattered signals to high amplitude signals reflected from structure features, such as planar surfaces. This makes identifying and characterizing such defects directly from ultrasonic images difficult. Here, a method is proposed to extract the small scattered signals from a near-surface defect within a full matrix capture data. The extracted signals were then used to generate a scattering matrix, from which it is possible to characterize the defect. In the proposed method, the location of the defect was first approximately identified from the image. The arrival time difference between the signals from the defect and the surface for each combination of transmitter and receiver array elements was then calculated. Some scattered signals can be directly separated, and the others were extracted by subtracting the data with reference signals from the surface, obtained in the absence of a defect. Finally, the proposed method was used to experimentally detect and characterize three different near-surface defects and improved measurements were achieved.

10:50 AM

Depth Measurement of Small Surface-Breaking Cracks Using the Half-Skip Total Focusing Method

---**Maria V. Felice**, Alexander Velichko, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol BS8 1TR, United Kingdom; Christopher J. Lane, Rolls-Royce plc., NDE Laboratory, Derby, United Kingdom

---The Total Focusing Method (TFM) is an ultrasonic array post-processing technique which is used to synthetically focus at every image point in a target region. Typically, only direct ray paths between the array and image points are included in the TFM algorithm. Therefore, when inspecting for cracks which have initiated from the far surface of a parallel-sided sample using an array on the near surface, the TFM image obtained consists only of root and tip indications; no specular reflection from the crack faces is captured. The tip indication often has such a poor signal-to-noise ratio that reliable crack depth measurement is challenging. In this paper, the half-skip configuration of the TFM is used to image and size surface-breaking cracks. With the Half-Skip TFM, instead of using directly-scattered signals, the image is formed using ultrasonic ray paths corresponding to the ultrasound that has reflected off the back surface and then undergone specular reflection from the crack face back to the array. The technique is applied to experimental and simulated array data for small cracks (depth < 2 wavelengths) and improved depth measurements are obtained compared with using the conventional TFM. A practical trial using the Half-Skip TFM on fatigue cracks in a noisy material is also presented.

11:10 AM

Resolution Enhancement of Subharmonic Phased Array Using MUSIC Algorithm
---**Choon-Su Park**, Jun-Woo Kim, Seunghyun Cho, and Dae-Cheol Seo, Korea Research Institute of Standards and Science (KRISS), Division of Metrology for Quality of Life, 267 Gajeong-ro, Yuseong-gu, Daejeon, 305-340

---Closed cracks are hardly detected by conventional ultrasonic testing, since most incident ultrasound passes through them. Nonlinear ultrasound inspection using sub-harmonic frequency has been proved to be a promising way to detect the closed cracks. In addition, sub-harmonic phased array (PA) was proposed to visualize how far the closed cracks stretch out in solids. The sub-harmonic PA inherently has lower resolution than the fundamental frequency PA images, because wavelength is two times longer than the fundamental one. The maximum peak of main-lobe represents a possible source location, and main-lobe beamwidth depends on the frequency of interest. The beamwidth becomes broad as frequency goes lower. The broad main-lobe often prevents from identifying where a source is. For more than half a century, it has been developed to improve spatial resolution of beamforming images. In particular, MUSIC (MUltiple SIgnal Classification) is a well-defined way to make the resolution better by using the orthogonal property between signal of interest and noise inherently embedded in the signal measured. Phased array imaging with the MUSIC algorithm is examined and simulated to verify whether it is applicable to sub-harmonic imaging. In addition, some experiments with CT specimens have been done to show closed-crack localization by improving resolution of sub-harmonic imaging with the MUSIC.

11:30 AM

Development of Confocal Subharmonic Phased Array for Crack Evaluation for Closed Crack Imaging and Analyses of Nonlinear Scattering Behaviors
---**Yoshikazu Ohara**, Azusa Sugawara, Kentaro Jinno, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---To solve the problem of closed cracks, we have developed an imaging method, subharmonic phased array for crack evaluation (SPACE) [Ohara, et al., APL, 2007]. A single-array SPACE [Ohara, et al., JJAP, 2012] has an advantage of compactness but it can image only the vicinity of the transmission focal point (TFP) when the TFP is fixed. In this study, we have developed a confocal SPACE to image closed cracks in a wide area. The confocal SPACE defines multiple TFPs. For each TFP, the fundamental array (FA) and subharmonic array (SA) images are created based on the SPACE imaging algorithm. By merging these images to an image, closed cracks in a wide area can be visualized. To verify it, we measured a stress corrosion crack (SCC) formed in high temperature pressurized water. The SCC was not observed in the merged FA image either due to its perfect closure or due to the disturbance by linear scatterings at coarse grains, whereas SCCs were clearly observed as bright spots in the merged SA image. Thus we verified that the confocal SPACE is useful in measuring closed-crack depths. Furthermore, to observe the scattering behaviors in detail, we developed a radar-like display, which superimposes a line including the TFP and the center of array transducer on an image for each TFP, where the incidence angle is varied. As a result, moving crack response (MCR) following the motion of the line was observed in SA images. It can be assumed that MCR is caused by the change in crack opening point (COP) where the crack closure stress is equal to the tensile stress of incident wave. To verify the assumption, we conducted a simulation using a damped double node (DDN) model [Yamanaka, et al., APEX, 2011]. As a result, MCR was reproduced and the change in COP with varying incidence angles was observed. Thus the observation and analysis of MCR will be useful in estimating crack closure stress.

11:50 AM

Full-Matrix Capture on Customizable Ultrasonic Phased Array Instrument
---**Gavin Dao**, Advanced OEM Solutions, 8044 Montgomery Road #700, Cincinnati, OH 45236; Matt Gruber, The Phased Array Company (TPAC), 9277 Centre Pointe Dr. #350, West Chester, OH 45069

---In recent years, a technique known as Full-Matrix Capture (FMC) has gained some headway in the NDE community for phased array applications. It’s important to understand that FMC is the method that the instrumentation acquires the ultrasonic signals, but further post-processing is required in software to create a meaningful image for a particular application. Having a flexible software interface, small form factor, and excellent signal-to-noise ratio per acquisition channel on a 64/64 or 128/128 phased array module with FMC capability proves beneficial in both industrial implementation and in further investigation of post-processing techniques. This paper will provide an example of imaging with a 5MHz linear phased array transducer with 128 elements using FMC and a popular post-processing algorithm known as Total Focus Method (TFM).

Session 8

SESSION 8
CIVIL STRUCTURES AND CONCRETE
Dwight A. Clayton, Chairperson
Pines-Willows

8:30 AM **Near Field Effects and Estimation of Poisson's Ratio in Impact-Echo Thickness Testing**
---**Oskar Baggens** and Nils Rydén, Division of Engineering Geology, Lund University, S-221 00 Lund, Sweden

8:50 AM **Non-Contact Excitation of Fundamental Resonance Frequencies of an Asphalt Concrete Specimen**
---**Anders Gudmarsson**, Nils Ryden, and Björn Birgisson, KTH Royal Institute of Technology, Highway and Railway Engineering, 100 44 Stockholm, Sweden

9:10 AM **Guided Wave Approach and Energy Attenuation with Fully Contactless Ultrasonic System to Characterized Reinforced Concrete Structure**
---**Suyun Ham** and John S. Popovics, The University of Illinois, Urbana-Champaign, Civil and Environmental Engineering, Urbana, IL 61874

9:30 AM **Ultrasonic Linear Array Validation via Concrete Test Blocks**
---**Kyle Hoegh** and Lev Khazanovich, University of Minnesota, Department of Civil Engineering, 500 Pillsbury Dr. SE, Minneapolis, MN 55455; Chris Ferraro, University of Florida, Department of Civil and Coastal Engineering, Gainesville, FL 32611; Dwight Clayton, Oak Ridge National Laboratories, Measurement Science and Systems Engineering Division, Oak Ridge, TN 37831

9:50 AM **The Benefits of Using Time-Frequency Analysis with Synthetic Aperture Focusing Technique**
---Austin P. Albright and **Dwight A. Clayton**, Oak Ridge National Laboratory, Electrical and Electronics Systems Research Division, Oak Ridge, TN 37831

10:10 AM ***Break***

10:30 AM **Three-Dimensional Ultrasonic Imaging of Concrete Elements Using Different SAFT Data Acquisition and Processing Schemes**
---**Martin Schickert**, Materialforschungs- und -prüfanstalt an der Bauhaus-Universität Weimar (MFPA Weimar), Coudraystr. 9, Weimar 99423, Germany

10:50 AM **Ground-Penetrating Radar Measurements of Attenuation in Concrete**
---**David Eisenmann**, Brittney Pavel, and Frank Margetan, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

11:10 AM **Best Practices for Embedding Sensors in Concrete for the Evaluation of NDE Methodologies**
---**Dwight A. Clayton** and Roberto Lenarduzzi, Oak Ridge National Laboratory, Electrical and Electronics Systems Research Division, Oak Ridge, TN; Halil Ceylan, Iowa State University, Department of Civil, Construction and Environmental Engineering, Ames, IA; Yann M. Le Pape, Oak Ridge National Laboratory, Fusion and Materials for Nuclear Systems, Oak Ridge, TN 37831

11:30 AM **Effects of Alkali-Silica Reaction on the Propagation of Ultrasound in Concrete**
---**Taeho Ju**, Shuaili Li, Jan Achenbach, and Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

11:50 AM **Micro-XCT Study of the Interfacial Zone Properties of Old-to-New Concrete Interfaces**
---**Yang Lu**, Boise State University, Department of Civil Engineering, 1910 University Dr., Boise, ID 83725; Danni Luo and Qianjun Xu, Tsinghua University, Department of Hydraulic and Hydropower Engineering, 100084, China; Edward J. Garboczi, National Institute of Standards and Technology, Materials and Structural Systems Division, Gaithersburg, MD 20899-8615

12:10 PM ***Lunch***

8:30 AM

Near Field Effects and Estimation of Poisson's Ratio in Impact-Echo Thickness Testing

---**Oskar Baggens** and Nils Rydén, Division of Engineering Geology, Lund University, S-221 00 Lund, Sweden

---Reliable non-destructive estimation of thickness for plate-like concrete structures is important by many aspects such as maintenance planning, manufacturing, quality control, pay factor, safety etc. One commonly used method, for a non-destructive estimation of thickness, is the Impact-Echo (IE) method [1]. More recent studies have established the connection between the Impact-Echo method and Lamb wave theory [2]. In Lamb wave theory a plate is defined by three independent parameters (e.g. shear wave speed, Poisson's ratio and thickness). Consequently, the Impact-Echo frequency must be complemented with one velocity (compression or shear wave velocity) and Poisson's ratio for the best possible estimation of thickness. One possibility is to combine the Impact-Echo method and surface wave analysis [3]. In this paper the influence from near field effects (cylindrical spreading of waves from a point source, and interference of different wave modes) are studied for this approach. The near field effects are found to create a systematic error which underestimates the thickness with 5-15%. Results indicate that the main source of error is related to the inherently difficult task of measuring a representative compression wave velocity along the surface. Therefore, alternative approaches which are not based on measurements of the compression wave velocity are investigated for improved accuracy of the estimated thickness.---The Development Fund of the Swedish Construction Industry (SBUF) and The Swedish Radiation Safety Authority (SSM) are acknowledged for financing the study.

References:

1. M. J. Sansalone and W. B. Streett, Impact-echo: Non-destructive Evaluation of Concrete and Masonry. Bullbrier Press, 1997.
2. A. Gibson and J. Popovics, "Lamb wave basis for impact-echo method analysis," J. Eng. Mech., pp. 1–6, 2005.
3. N. Ryden and C. Park, "A combined multichannel impact echo and surface wave analysis scheme for non-destructive thickness and stiffness evaluation of concrete slabs," AS NT, 2006 NDE Conf. Civ. Eng., pp. 247–253, 2006.

8:50 AM

Non-Contact Excitation of Fundamental Resonance Frequencies of an Asphalt Concrete Specimen

---**Anders Gudmarsson**, Nils Ryden, and Björn Birgisson, KTH Royal Institute of Technology, Highway and Railway Engineering, 100 44 Stockholm, Sweden

---The strong temperature dependency of asphalt concrete makes it important to limit any temperature variations during testing of the viscoelastic material properties as e.g. the complex modulus. Ideally, measurements should be performed inside a temperature chamber without disturbing the climate in the chamber. Conventional methods based on cyclic loading can be performed in a closed regulated chamber while new, more economic, nondestructive impact resonance test methods often requires at least an opening of the chamber to perform the testing. Non-contact excitation of asphalt concrete makes it possible to eliminate any disturbance to the temperature and at the same time automatically perform measurements. Furthermore, non-contact excitation enables detailed measurements to investigate potential nonlinearities of asphalt concrete at strain levels lower than the possible measurement range of conventional test methods (i.e. ~10-6). In this paper, a speaker is used to excite the fundamental resonance frequencies of a disc-shaped asphalt concrete specimen (diameter of 150 mm and thickness of 30 mm) at different fixed temperatures. The response of the asphalt concrete to different amplitudes can be carefully examined without any interference of temperature changes. Results show that the resonance frequencies excited by the speaker at the different temperatures agrees with those excited by an impact hammer. In addition, the results demonstrate that the accuracy of the measurements opens up the possibility to study nonlinear properties of asphalt concrete such as slow dynamics, damage detection, aging and healing.---The Swedish transport administration (Trafikverket) and the Swedish construction industry's organization for research and development (SBUF) are acknowledged for their financial support.

9:10 AM

Guided Wave Approach and Energy Attenuation with Fully Contactless Ultrasonic System to Characterized Reinforced Concrete Structure

---**Suyun Ham** and John S. Popovics, The University of Illinois, Urbana-Champaign, Civil and Environmental Engineering, Urbana, IL 61874

---Ultrasonic techniques provide an effective non-destructive evaluation (NDE) method to monitor concrete structures, but the need to perform rapid and accurate interpretation assessment requires evaluation of hundreds, or even thousands, of measurement data. Use of a fully contactless ultrasonic system can save time and labor through rapid implementation, and can enable automated and controlled data acquisition for example through robotic scanning. The fully contactless ultrasonic system consists of both air-coupled electrostatic transducer and air-coupled MEMS sensor. This paper describes our efforts to develop contactless surface wave system for NDE of concrete in structures. The developed contactless sensors, controlled scanning system with mobile apparatus and employed signal processing scheme are described. Our fully contactless system is used for detecting delaminations with guided wave approach and characterizing the level of microcracked concrete with energy attenuation. The concrete delamination are interpreted in terms of guided plate wave (Lamb wave) theory carried out on full-scale concrete slabs. They are formed by coupled longitudinal and transverse wave motion and include an infinite number of individual symmetrical (S) and anti-symmetric (A) solution modes. Each Lamb mode has a distinct phase velocity, which unlike the body and surface waves, is dispersive (i.e. is a function of frequency). Also, energy loss (attenuation) is a good indicator of distributed cracks in concrete. Therefore, our ultrasonic system showed a sensitive detector of delamination and level of microcracking in concrete providing many consistent data.

9:30 AM

Ultrasonic Linear Array Validation via Concrete Test Blocks

---**Kyle Hoegh** and Lev Khazanovich, University of Minnesota, Department of Civil Engineering, 500 Pillsbury Dr. SE, Minneapolis, MN 55455; Chris Ferraro, University of Florida, Department of Civil and Coastal Engineering, Gainesville, FL 32611; Dwight Clayton, Oak Ridge National Laboratories, Measurement Science and Systems Engineering Division, Oak Ridge, TN 37831

---Oak Ridge National Laboratories (ORNL) comparatively evaluated the ability of a number of NDE techniques to generate an image of the volume of 6.5’ X 5.0’ X 10” concrete specimens fabricated at the Florida Department of Transportation (FDOT) NDE Validation Facility in Gainesville, Florida. These test blocks were fabricated to test the ability of various NDE methods to characterize various placements and sizes of rebar as well as simulated cracking and non-consolidation flaws. The first version of the ultrasonic linear array device, MIRA [version 1], was one of 7 different NDE equipment used to characterize the specimens. This paper deals with the ability of this equipment to determine subsurface characterizations such as reinforcing steel relative size, concrete thickness, irregularities, and inclusions using Kirchoff-based migration techniques. The ability of individual synthetic aperture focusing technique (SAFT) B-scan cross sections resulting from self-contained scans are compared with various processing, analysis, and interpretation methods using the various features fabricated in the specimens for validation. The performance is detailed, especially with respect to the limitations and implications for evaluation of a thicker, more heavily reinforced concrete structures. Discussion of the type of large, heavily reinforced specimen required to determine the strengths and limitations for representative nuclear power plant containment walls is also explored.

9:50 AM

The Benefits of Using Time-Frequency Analysis with Synthetic Aperture Focusing Technique

---Austin P. Albright and **Dwight A. Clayton**, Oak Ridge National Laboratory, Electrical and Electronics Systems Research Division, Oak Ridge, TN 37831

---Improvements in detection and resolution are always desired and needed. There are various instruments available for the inspection of concrete structures that can be used with confidence for detecting different defects. However, more often than not that confidence is heavily dependent on the experience of the operator rather than the clear, objective discernibility of the output of the instrument. The challenge of objective discernment is amplified when the concrete structures contain multiple layers of reinforcement, are of significant thickness, or both, such as concrete structures in nuclear power plants. We seek to improve and extend the usefulness of results produced using the synthetic aperture focusing technique (SAFT) on data collected from thick, complex concrete structures. With the additional goal of improving existing SAFT results, with regards to repeatedly and objectively identifying defects and/or internal structure of concrete structures. Towards these goals, we are applying the time-frequency technique of wavelet packet decomposition and reconstruction using a mother wavelet that possesses the exact reconstruction property. However, instead of analyzing the coefficients of each decomposition node, we select and reconstruct specific nodes based on the frequency band it contains to produce a frequency band specific time-series representation. SAFT is then applied to these frequency specific reconstructions allowing SAFT to be used to visualize the reflectivity of a frequency band and that band's interaction with the contents of the concrete structure. We apply our technique to data sets collected using a commercial, ultrasonic linear array (MIRA) from two 1.5m x 2m x 25cm concrete test specimens. One specimen contains multiple layers of rebar. The other contains honeycomb, crack, and rebar bonding defect analogs. This approach opens up a multitude of possibilities for improved detection, readability, and overall improved objectivity. We will focus on improved defect/reinforcement isolation in thick and multilayered reinforcement environments. Additionally, the possibility of empirically exploring the possibility of a frequency-band-defect-type relationship or sensitivity becomes possible.

10:30 AM

Three-Dimensional Ultrasonic Imaging of Concrete Elements Using Different SAFT Data Acquisition and Processing Schemes
---**Martin Schickert**, Materialforschungs- und -prüfanstalt an der Bauhaus-Universität Weimar (MFPA Weimar), Coudraystr. 9, Weimar 99423, Germany

---Ultrasonic testing systems using transducer arrays and the SAFT (Synthetic Aperture Focusing Technique) algorithm allow for imaging the internal structure of concrete elements. At one-sided access, three-dimensional representations of the concrete volume can be reconstructed in relatively great detail, permitting to detect and localize objects such as construction elements, built-in components, and flaws. The reconstruction quality of the SAFT images is dependent on various parameters of the measuring system and the concrete properties. With given concrete properties, SAFT data acquisition and processing schemes can be optimized. In this contribution, different SAFT data acquisition and processing schemes are discussed with respect to image resolution, signal-to-noise ratio, measurement time, and computational effort. The dependencies of these parameters are demonstrated using the automated SAFT imaging system FLEXUS which includes a three-axis scanner with a 1.0 m x 0.8 m scan range and an electronically switched ultrasonic array with 48 transducers in 16 channels. On the basis of measurements at test specimens, the conventional single-channel SAFT algorithm is compared with the Combinational SAFT algorithm (SAFT-C, also referred to as Full Matrix Capture/Total Focusing Method – FMC/TFM) for single and multiple track measurements. Additional results of field measurements show SAFT imaging possibilities under practical conditions. As an outlook, a 120-channel ultrasonic tomography system is described which was recently finalized.

10:50 AM

Ground-Penetrating Radar Measurements of Attenuation in Concrete
---**David Eisenmann**, Brittney Pavel, and Frank Margetan, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Ground-penetrating radar (GPR) signals from concrete structures are affected by several phenomenon, including: (1) transmission and reflection coefficients at interfaces; (2) the radiation patterns of the antenna(s) being used; and (3) the material properties of concrete and any embedded objects. In this paper we investigate different schemes for determining the electromagnetic (EM) attenuation of concrete from measured signals obtained using commercially-available GPR equipment. We adapt procedures commonly used in ultrasonic inspections where one compares the relative strengths of two or more signals having different travel paths through the material of interest. After correcting for beam spread (diffraction), interface phenomena, and equipment amplification settings, any remaining signal differences are assumed to be due to attenuation thus allowing the attenuation coefficient (in dB of loss per inch of travel) to be estimated. We begin with a brief overview of our approach, and then discuss how diffraction corrections were determined using two 1.6 GHz GPR antennas. We then present results of attenuation measurements for two types of concrete using both pulse/echo and pitch/catch measurement setups.---This material is based upon work supported by Iowa State University’s Institute for Physical Research and Technology’s Seed Funding and performed at Iowa State University’s Center for NDE.

11:10 AM

Best Practices for Embedding Sensors in Concrete for the Evaluation of NDE Methodologies

---**Dwight A. Clayton** and Roberto Lenarduzzi, Oak Ridge National Laboratory, Electrical and Electronics Systems Research Division, Oak Ridge, TN; Halil Ceylan, Iowa State University, Department of Civil, Construction and Environmental Engineering, Ames, IA; Yann M. Le Pape, Oak Ridge National Laboratory, Fusion and Materials for Nuclear Systems, Oak Ridge, TN 37831

---Extending a nuclear power plant license to 60 years and beyond will likely increase susceptibility and severity of known forms of degradation. Unlike most metallic materials, reinforced concrete is a nonhomogeneous material, a composite with low-density matrix, a mixture of cement, sand, aggregate and water, and a high density reinforcement made of steel rebar or tendons. With respect to the concrete structures in nuclear power plants, age and environmental degradation may affect engineering properties, structural resistance/capacity, failure mode, and locations of failure initiation that in turn may affect the ability of a structure to withstand challenges in service. In contrast to many mechanical and electrical components, replacement of concrete structures is currently considered impractical. Therefore it is necessary that safety issues related to plant aging and concrete structures are resolved through sound scientific and engineering understanding. The evaluation of measurements of material properties using nondestructive evaluation methods, to be effective, relies on a comprehensive understanding of the internal degradation process of the specimen under test. For this reason, researchers use material specimens that are constructed to be representative of the material for which the evaluation methods and sensors are designed to test. These specimens include sensors that are embedded to measure physical parameters from which to draw conclusions on the internal condition of the material. In the case of concrete, several physical parameters are of interest as the entire curing and aging process of the concrete composition as well as the probable environmental degradation affect them. This paper presents a set of best practices for embedding sensors in concrete for an Alkali-Silica Reaction (ASR) test specimen. Particular attention is placed in protecting the sensors from wet and chemical conditions and in positioning them in order to obtain reliable measurements while not compromising the structure of the concrete and minimizing their effect on measurements performed by other external sensors. Sensors included in this discussion are used to measure strain, humidity and temperature. For the measurement of some of the physical properties, different sensors exhibiting different measurement characteristics are used.

11:30 AM

Effects of Alkali-Silica Reaction on the Propagation of Ultrasound in Concrete
---**Taeho Ju**, Shuaili Li, Jan Achenbach, and Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

---Alkali-silica reaction (ASR) is a chemical reaction prevalent in concrete structures. In the presence of moisture, alkaline ions in the cement are dissolved in and transported to the aggregates by the diffusing moisture. In contact, alkaline ions react with the silica in the aggregates, and the reaction produces a silica gel. The silica gel imbibes moisture and swells. Gel swelling induces internal pressure. As a result, the concrete may expand in volume, and even fracture. Such ASR damage is a major deterioration mechanism in concrete structures. To develop nondestructive ultrasonic techniques for monitoring ASR damage, it is necessary to understand how ultrasonic propagation is affected by ASR damage. In this work, concrete samples are made by mixing silica glass beads and type I cement. The samples are immersed in alkaline solutions with different concentrations at various temperatures. Ultrasonic measurements are carried out on these samples periodically and the results are plotted as function of immersion time. The ultrasonic measurement results include phase velocity, attenuation and the acoustic nonlinearity parameter. Optical microscopy is also conducted to investigate the correlations between ASR-induced microstructural damage and the measured ultrasonic results.

11:50 AM

Micro-XCT Study of the Interfacial Zone Properties of Old-to-New Concrete Interfaces

---**Yang Lu**, Boise State University, Department of Civil Engineering, 1910 University Dr., Boise, ID 83725; Danni Luo and Qianjun Xu, Tsinghua University, Department of Hydraulic and Hydropower Engineering, 100084, China; Edward J. Garboczi, National Institute of Standards and Technology, Materials and Structural Systems Division, Gaithersburg, MD 20899-8615

---Many civil infrastructures involve bonded old-and-new concrete engineering, such as buildings, transportation infrastructures, and dams. The interfacial bonding may have a direct impact on the engineering quality. After a period in service, the interface forms a discontinuity and serves as a weak/damage zone that is relatively weaker than both sides of the concrete. Thus, concrete structure is likely to fail along the interfacial regions because of weak layers, flaws, micro-cracks, and rapid change of stress level along the interface. Many attempts have tried to characterize the interfacial weak zone behaviors experimentally, but no microstructural analysis based on X-ray Tomography (CT) has been performed yet. In this study, both experimental and digital image analysis methods are performed to study the relationship between interface roughness and micro defects. The concrete samples were made in the laboratory to reproduce the concrete joints using casted new-to-old concrete specimens. A series of cores were drilled from the interfacial zones covering new concrete, interface, and old concrete in the radial plane. Micro X-ray computed tomography (CT), a non-destructive and non-invasive imaging technique, was employed to examine the damage zone at a resolution of 20 micrometers. Digital images were processed and analyzed to obtain three-dimensional (3-D) information of the weak zone microstructure at representative drilled core samples. The segmented two-dimensional (2-D) image data was used to quantify the micro defects, e.g. porosity, interfacial defects transition zone size, and 2-D micro cracks configuration. Furthermore, 3-D microstructure reconstruction was also performed to quantify the crack morphology.

Session 9

Tuesday, July 22, 2014

SESSION 9
RADIOGRAPHY I
Uwe Ewert and Joseph N. Gray, Co-Chairpersons
Cottonwoods-Firs

8:30 AM **Toward Practical 3D Radiography on Pipeline Girth Welds**
---**Casper Wassink**, Arjan Flikweert, Martijn Hol, and Philip van Meer, Applus RTD, Technological Center, Delftweg 144, 3046NC Rotterdam, The Netherlands

8:50 AM **X-Ray Tomographic In-Service Inspection of Girth Welds – the European Project TomoWeld**
---**Uwe Ewert**, Bernhard Redmer, David Walter, Kai-Uwe Thiessenhusen, and Carsten Bellon, BAM-Bundesanstalt für Materialforschung und –prüfung, Unter den Eichen 87, 12205 Berlin, Germany; Pascual Ian Nicholson and Alan Clarke, TWI Ltd, Cambridge, United Kingdom; Klaus-Peter Finke-Härkönen, Oy AJAT Ltd., Finland

9:10 AM **Industrial Applications of Automated X-Ray Inspection**
---**Shashishekhar Nagabhushana**, V. J. Technologies, Inc., Research & Development, Bohemia, NY 11716

9:30 AM **Active Investigation of Material Damage Under Load Using X-ray Micro-CT**
---**Megha Navalgund**, S. Zunjarrao, V. Manoharan and Debasish Mishra, GE Global Research, GE India Technology Centre, Pvt. Ltd. 122, EPIP, Hoodi Village, Whitefield Road, Bangalore, India

9:50 AM **Recent Progress in 3-D Imaging of Sea Freight Containers**
---**Theobald O. J. Fuchs**[1], Tobias Schön[1], Frank Sukowski[1], Jonas Dittmann[2] and Randolf Hanke[2], [1]Fraunhofer Development Center X-ray Technology, EZRT, Fuerth, Bavaria, Germany; [2]Julius-Maximilian-University, Institute of Physics and Astronomy, Chair for X-ray Microscopy, Wuerzburg, Bavaria, Germany

10:10 AM ***Break***

10:30 AM **Observer POD for Radiographic Testing**
---**Daniel Kanzler**, Uwe Ewert, Christina Müller, and Marija Bertovic, BAM Federal Institute for Materials Research and Testing; Berlin, Germany; Jorma Pitkänen, Posiva Oy; Eurajoki, Finland

10:50 AM **Use of XRSIM on Generation POD Hit Miss Data**
---**Joe Gray** and Irving Gray*, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; *NDE Technologies

11:10 AM **Microstructured Optical Fiber Containing Alkali Halide Scintillating Material for X-Ray Detection**
---**Stanton L. DeHaven** and Russell A. Wincheski, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681; Sacharia Albin, Norfolk State University, Engineering Department, Norfolk, VA 23501

11:30 AM **Fast Model of Electron Transport for Radiographic Spectrum Simulation**
---**Andreas Deresch**, Carsten Bellon, Gerd-Rüdiger Jaenisch, and Uwe Ewert, BAM Federal Institute for Materials Research and Testing, Division 8.3 Radiological Methods, Berlin, Germany

11:50 AM **The Impact of Camouflage Effects on Detectability**
---**Joe Gray**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

12:10 PM **Retention of Cast Turbine Blades for Computed Tomograpy (CT) Metrology**
---**Surendra Singh**[1], David Waldman[2], Mark Morris[2], Malak Malak[2], and Andy Kinney[1], [1] NDT Engineering, Materials & Process Engineering; [2] Advanced Technology; Honeywell Aerospace, Phoenix, AZ 85034

12:30 PM ***Lunch***

8:30 AM

Toward Practical 3D Radiography on Pipeline Girth Welds
---**Casper Wassink**, Arjan Flikweert, Martijn Hol, and Philip van Meer, Applus RTD, Technological Center, Delftweg 144, 3046NC Rotterdam, The Netherlands

---Digital radiography has made its way into in-the-field girth weld testing. With recent generations of detectors and tubes it is possible to reach the image quality desired in standards as well as the speed of inspection desired to be competitive with film radiography and automated ultrasonic testing. This paper will show the application of these technologies in the Rayscan system. The method for achieving an image quality that complies with or even exceeds prevailing industrial standards will be presented, as well as the application on pipeline girth welds with CRA layers. A next step in development will be to also achieve a measurement of weld flaw height to allow for performed an Engineering Critical Assessment on the weld. This will allow for similar acceptance limits as currently used with Automated Ultrasonic Testing of pipeline girth welds. Although a sufficient sizing accuracy was already demonstrated and qualified in the TomoCAR system, testing in some applications is restricted to time limits. The paper will present some experiments that were performed to achieve flaw height approximation within these time limits.

8:50 AM

X-Ray Tomographic In-Service Inspection of Girth Welds – the European Project TomoWeld

---**Uwe Ewer**t, Bernhard Redmer, David Walter, Kai-Uwe Thiessenhusen, and Carsten Bellon, BAM-Bundesanstalt für Materialforschung und –prüfung, Unter den Eichen 87, 12205 Berlin, Germany; Pascual Ian Nicholson and Alan Clarke, TWI Ltd, Cambridge, United Kingdom; Klaus-Peter Finke-Härkönen, Oy AJAT Ltd., Finland

---The new standard 'ISO 17636-2-2013: Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors', defines the practice for radiographic inspection of welded pipes for manufacturing and in-service inspection. It is applied in Europe for inspections of pipes in nuclear power plants and in chemical plants. This allows a faster inspection with digital detector arrays (DDA) than with film. Nevertheless, it does not allow the evaluation of the depth and shape of volumetric and planar indications. In 2006 a planar tomography scanner, TomoCAR [1, 2], was introduced for mechanized radiographic testing (RT)-inspection and measurement of non-destructive cross sections. The project TomoWeld is based on a new concept of the scan geometry, an enhanced GPU based reconstruction and the application of a new generation of photon counting DDAs based on CdTe Crystal CMOS Hybrids. The new detector permits the selection of energy thresholds to obtain an optimum energy range and reduction of the influence of scattered radiation. The concept and first measurements are presented. Flaw depth and shape of volumetric and planar irregularities can be determined.

References:

1. Bernhard Redmer, Uwe Ewert, Burkhard Neuendorf, Michael Jakob, 9th ECNDT, 25. – 29. Sept. 2006, Berlin, Germany, http://www.ndt.net/article/ecndt2006/doc/We.3.2.3.pdf.
2. Uwe Ewert, Bernhard Redmer Christoph Rädel, Ulf Schnars, Rudolf Henrich, Klaus Bavendiek and Mirko Jahn, Materials Transactions, Vol. 53, No. 2 (2012) pp. 308 to 310.

9:10 AM

Industrial Applications of Automated X-Ray Inspection
---**Shashishekhar Nagabhushana**, V. J. Technologies, Inc., Research & Development, Bohemia, NY 11716

---Many industries require that 100% of manufactured parts be X-ray inspected. Factors such as high production rates, focus on inspection quality, operator fatigue, and inspection cost reduction, translate to an increasing need for automating the inspection process. Automated X-ray inspection involves the use of image processing algorithms and computer software for analysis and interpretation of X-ray images. This paper presents industrial applications and illustrative case studies of automated X-ray inspection in areas such as castings, fuel cells, air-bag inflators, tires, and munitions inspection. It is usually necessary to employ application-specific automated inspection strategies and techniques, since each application has unique characteristics and interpretation requirements.

9:30 AM

Active Investigation of Material Damage Under Load Using X-ray Micro-CT
---**Megha Navalgund**, S. Zunjarrao, V. Manoharan and Debasish Mishra, GE Global Research, GE India Technology Centre, Pvt. Ltd. 122, EPIP, Hoodi Village, Whitefield Road, Bangalore, India

---Due the growth of composite materials across multiple industries such as Aviation, Wind there is an increasing need to not just standardize and improve manufacturing processes but also to design these materials for the specific applications. In other words design-for- reliability for composites. One of the things that this translates into, is understanding how failure initiates and grows in these materials and at what loads, especially around internal flaws such as voids or features such as ply drops. Traditional methods of investigating internal damage such as CT lack the resolution to resolve ply level damage in composites. Interrupted testing with layer removal can be used to investigate internal damage using microscopy; however this is a destructive method. Advanced techniques such as such as DIC are useful for in-situ damage detection, however are limited to surface information and would not enable interrogating the volume Computed tomography has become a state of the art technique for metrology and complete volumetric investigation especially for metallic components. However, its application to the composite world is still nascent. This paper explores micro-CT and nano-CT as a gauge to quantitatively estimate the extent of damage & understand the propagation of damage in the volume while the component is under stress. In addition to being non-destructive it enables the ability to ‘see’ the damage while being loaded, hence the term active. This paper will discuss, optimization studies performed to enable the micro-CT technique and work done to characterize damage around sub-surface features through testing with in-situ CT characterization on PMC composites. A comparison of these results with DIC technique and layer removal method will also be presented.

9:50 AM

Recent Progress in 3-D Imaging of Sea Freight Containers

---**Theobald O. J. Fuchs**[1], Tobias Schön[1], Jonas Dittmann[2], Frank Sukowski[1], and Randolf Hanke[2], [1]Fraunhofer Development Center X-ray Technology, EZRT, Fuerth, Bavaria, Germany; [2]Julius-Maximilian-University, Institute of Physics and Astronomy, Chair for X-ray Microscopy, Wuerzburg, Bavaria, Germany

---The inspection of sea freight containers with Computed Tomography (CT) machines built to capture extremely large (XXL-CT) volumes is an emerging technology. The benefits of 3-D X-ray imaging of sealed freight is obvious: potential threats or illicit cargo can be reliably detected without being confronted with legal complications, the high time consumption and the risks for the security personnel during a manual search. Today, a complete 3-D CT scan of a 20-feet-container takes more or less a few hours, depending on the envisaged spatial resolution and/or signal to noise ratio. Of course this is too slow to apply 3-D CT to a large number of containers. Thus, only suspicious containers, which have been tested with fast 2-D radiography, but with ambiguous result, are passed to the 3-D stage. Yet, recently distinct progress was made in the field of reconstruction of projections with only a relatively low number of angular positions. Instead of today's 500 to 1000 rotational steps, as needed for conventional CT reconstruction techniques, this new class of algorithms provides the potential to reduce the number of angels approximately by a factor of 10. The only drawback of these advanced iterative methods is the high consumption for numerical processing. But as computational power is getting steadily cheaper, there will be practical applications of these complex algebraic algorithms in a foreseeable future. In our presentation we will discuss the properties of iterative image reconstruction algorithms and show results of their application to CT of extremely large objects like the freight containers mentioned above.

10:30 AM

Observer POD for Radiographic Testing
---**Daniel Kanzler**, Uwe Ewert, Christina Müller, and Marija Bertovic, BAM Federal Institute for Materials Research and Testing; Berlin, Germany; Jorma Pitkänen, Posiva Oy; Eurajoki, Finland

---The radiographic testing (RT) is a non-destructive testing (NDT) method capable of finding volumetric defects and open planar defects depending on its orientation. The radiographic contrast is higher for larger penetrated length of the defect in a component. Even though, the detectability of defects in its turn is not only depending on the contrast, but also on the noise, the defect area and its geometry. The currently applied Probability of Detection (POD) approach uses a detection threshold that is only based on a constant noise level or a constant contrast threshold. This does not reflect accurately the results of evaluations by human observers. A new approach is introduced, using the widely applied POD evaluation and additionally a detection threshold depending on the lateral area and shape of the indication. This work shows the process of calculating the POD curves with simulated data by the modeling software aRTist and with artificial reference data of different defect types, such as ASTM E 476 EPS plates, flat bottom holes and notches. Additional experiments with different operators confirm that the depth of a defect, the lateral area and shape of its indication contribute with different weight to the detectability of the defect if evaluated by human operators on monitors.

10:50 AM

Use of XRSIM on Generation POD Hit Miss Data
---**Joe Gray and Irving Gray***, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; *NDE Technologies

---With the emergence of experimentally validated NDE simulation tools capable we have an opportunity to develop a probability of detection (POD) suitable for use in lifeing assessments in the same manner as experimentally determined POD results. There are several benefits as the simulation tools first is a significant reduction in cost and second due to the use of CAD models for parts, defects shapes and the general ability to place defects anywhere in the part give a freedom that typically isn't available in experimental studies. Simulators also provide a quick estimate in limits of detectability and the evaluation of sensitivity of parameters needed in the design of POD studies. We will present a procedure for generating data sets for X-ray POD studies for digital detectors. The input required in terms of variability in experimental parameters and defect distributions and the means to view 16 bit data will be discussed. Finally we will present experimental results of the model validation and discuss the limitations of both the simulation and experimental approaches to POD determinations.

11:10 AM

Microstructured Optical Fiber Containing Alkali Halide Scintillating Material for X-Ray Detection

---**Stanton L. DeHaven** and Russell A. Wincheski, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681; Sacharia Albin, Norfolk State University, Engineering Department, Norfolk, VA

---Microstructured optical fibers containing alkali halide scintillation materials of CsI(Na), CsI(Tl) and NaI(Tl) are presented. The scintillation materials are grown inside the microstructured fibers using a modified Bridgman-Stockbarger technique. The x-ray photon counts of these fibers, with and without an aluminum thin film coating, are compared to the output of a collimated CdTe solid state detector over an energy range from 10 to 40 keV. The photon count results show significant variations in the fiber output based on the materials. The results and associated materials differences are discussed.

11:30 AM

Fast Model of Electron Transport for Radiographic Spectrum Simulation
---Andreas Deresch, Carsten Bellon, Gerd-Rüdiger Jaenisch, and Uwe Ewert, BAM Federal Institute for Materials Research and Testing, Division 8.3 Radiological Methods, Berlin, Germany

---Correctly modelling the continuous photon spectrum of X-ray sources requires detailed knowledge of the probability distribution of electron properties at the time of X-ray photon creation, in particular electron energy, depth within the target, and direction of movement. Semi-analytical X-ray spectrum models frequently assume a very simplified or even uniform distribution of electron direction. In the case of thick targets and small deviations from normal incidence this is a useful approximation. For thin targets or large deviations from normal incidence the correct distribution of electron directions becomes more important. As calculation speed is an important aspect of semi-analytical models compared to Monte Carlo simulations, fast evaluation of the distribution of electron properties is highly desirable. The approach presented here numerically evaluates the evolution of a discrete probability distribution of electron properties due to single electron scatter interactions within a plane target. This allows capturing the important aspects of the electron distribution while achieving runtimes of a few seconds up to a minute on a standard office PC.

11:50 AM

The Impact of Camouflage Effects on Detectability

---**Joe Gray**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Limits of detectability for a particular inspection protocol are influenced by a number pf parameters including equipment settings noise in the measurements, and part and defect shapes. With the increasing use of large array detectors, especially in x-ray inspections we often have multiple pixels imaging the defect. Noise enhanced imaging is not a notion that is commonly viewed as important in NDE inspections; however, with that advent of very small pixel sizes as compared to the defect size we have the situation where multiple pixels participate in the formation of the image of a defect, the impact of noise on detectability takes a different form. We will discuss the relationship between the amplitude of the defect signals versus the number of measurements and how as that number increases the bias in the noise allows detection of flaws with very small contrast to noise ratios. We will also discuss the importance of part shapes and defect morphology on the detectability noting that the human eye is particularly adept at picking out regular patterns in noise. The camouflage effect of small amplitude features in a part can significantly impact the limits of detection for a particular situation. We will show results of simulations and equivalent experimental data from digital detectors.---
This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

12:10 PM

Retention of Cast Turbine Blades for Computed Tomograpy (CT) Metrology
---**Surendra Singh**[1], David Waldman[2], Mark Morris[2], Malak Malak[2], and Andy Kinney[1], [1] NDT Engineering, Materials & Process Engineering; [2]Advanced Technology; Honeywell Aerospace, Phoenix, AZ 85034

---The increased demand for improved gas turbine system performance has motivated engineers and scientists alike to create innovative designs for new turbine blade and vane architectures for operating at higher temperature. The new designs often comprise multi-walls and internal features for improving the thermal effectiveness of the airfoils to maintain durability at the higher turbine cycle temperatures. The success of the airfoil depends on properly locating the multi-walls and internal features. Therefore, there is a need for Non Destructive Evaluation (NDE) technologies to provide accurate, fast, and economical measurements. X-ray Computed Tomography (CT) metrology offers such capability of consistently measuring internal geometry with desired accuracy and uncertainty. Proper fixturing of the airfoil complemented by optimum techniques and high-resolution detectors is critical to achieve the desired accuracy for acquiring CT dimensional data. This is due in part to the ability of the fixture to consistently locate the cast datum structure. Recent data show that prior art fixturing methods suffer from variability in locating the cast datum structure and from poor CT data as well. The latter is due to X-ray beam hardening, attenuation, and beam absorption in the Stereo Lithography Algorithm (SLA) material. The fixture described herein eliminates both datum variability and CT data degradation and offers improved measurement accuracy. It also simultaneously scans multiple blades, thereby significantly reducing inspection time to improve affordability in terms of throughput. The fixture discussed in this paper is for three blades, but the fixture can be modified for additional blades. The paper provides analysis of CT scanning Measurement System Evaluation (MSE), measurement error assessment, and Gage R&R (Repeatability and Reproducibility), in addition to correlation and comparative analyses of data from CT Metrology, structured light, CMM, and metallographic evaluation for several blades. Another motivation for the authors is to demonstrate the overall benefits of 3-D CT data versus conventional 2-D ultrasonic, structured light and physical cut up data.

Session 10

Tuesday, July 22, 2014

SESSION 10
NONCONTACT AND OPTICAL
Cara A. C. Leckey, Chairperson
Salmon-Snake

8:30 AM **Metal Cap Flexural Transducers for Air Coupled Ultrasonics**
---**Tobias J. R. Eriksson**, Steve M. Dixon, and Sivaram N. Ramadas, University of Warwick, Department of Physics, Coventry CV4 7AL, United Kingdom

8:50 AM **Determination of Surface Density of Nonporous Membranes with Air-Coupled Ultrasound**
---**Terence P. Lerch**, ET 100, Central Michigan University, School of Engineering and Technology, Mt. Pleasant, MI 48859

9:10 AM **An Approach for Defect Visualization and Identification in Composite Plate Structures Using Air-Coupled Guided Ultrasound**
---Rabi Sankar Panda, Prabhu Rajagopal, and **Krishnan Balasubramaniam**, Indian Institute of Technology, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

9:30 AM **Crack Investigation in the Far-Field of Laser Generated Surface Waves**
---Wei Wang, Zheng Zhong, and **Yongdong Pan**, School of Aerospace Engineering and Applied Mechanics, Tongji University, 100 Zhangwu Road, Shanghai 200092, China (PRC)

9:50 AM **Equivalent Body-Force Model for Magnetostrictive Transduction In EMATS**
---Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221; **Remo Ribichini**, GE Oil & Gas, TMS Service Engineering, Firenze, 50127, Italy

10:10 AM ***Break***

10:30 AM **Virtual Environment Assessment for Laser-Based Vision Surface Profiling**
---**Adnane O. ElSoussi**, Abed ElRahman K. Al Alami, and Bassam A. Abu-Nabah, American University of Sharjah, Department of Mechanical Engineering, Sharjah, United Arab Emirates

10:50 AM **Image Mosaicing for Automated Pipe Scanning**
---**Rahul Summan**, Gordon I. Dobie, Francesco Guarato, Charles N. MacLeod, Stephen Marshall, and S. Gareth Pierce, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, 204 George Street, Glasgow G1 1XW, United Kingdom; Cailean Forrester, Inspectahire Instrument Company Ltd, Aberdeen, United Kingdom

11:10 AM **Ultrasonic Near-Field Optical Microscopy Using a Plasmonic Nanofocusing Probe**
---**Oluwaseyi Balogun** and Xiang Chen, Department of Mechanical Engineering, Northwestern University, 2137 N. Tech Drive, Evanston, IL 60208

11:30 AM **Non-Destructive Evaluation by Digital Volumetric Speckle Photography (DVSP) Method**
---**H. Sam Huang** and Fu-Pen Chiang, Department of Mechanical Engineering, Stonybrook University, Stonybrook, NY 11794

11:50 PM ***Session Ends***

12:10 PM ***Lunch***

8:30 AM

Metal Cap Flexural Transducers for Air Coupled Ultrasonics

---**Tobias J. R. Eriksson**, Steve M. Dixon, and Sivaram N. Ramadas, University of Warwick, Department of Physics, Coventry CV4 7AL, United Kingdom

---Flexural transducers use the bending modes in a plate or membrane to effectively generate and receive ultrasonic waves in low impedance media. They have a characteristic frequency spectrum of narrowband peaks, corresponding to harmonic modes of vibration. The frequency of a specific mode is a function of the material, thickness and radius of the vibrating front face. Two different methods for actuating the transducer were investigated, using a piezoelectric disc bonded to the back of the plate, or by electromagnetic forces, generated by a current carrying coil close to the back (< 1 mm) of the plate. The transducer was characterized using laser interferometry, impedance analysis, and an acoustic microphone. Using a piezoelectric disk to drive the transducer relatively large displacements (100 nm) of the front face were observed for a small excitation voltage (1 V peak-to-peak). Using electromagnetic forces to actuate the transducer also produced large displacement amplitudes, but required a much greater excitation pulse. Different transducers actuated by non-contact methods show better consistency between transducers. Piezoelectrically actuated transducers had varied performance, which is likely due to inconsistent bonding of the piezoelectric disc. The measured resonance frequencies of the flexural transducer are comparable to the modal frequencies of an analytical plate model with clamped boundary conditions. The measured frequencies are in the band between the resonance frequencies of a clamped plate with the inner and outer radius of the flexural transducer.

8:50 AM

Determination of Surface Density of Nonporous Membranes with Air-coupled Ultrasound

---**Terence P. Lerch**, ET 100, Central Michigan University, School of Engineering and Technology, Mt. Pleasant, MI 48859

---The surface density or mass per unit area of a membrane is an important material property often used in acoustics and ultrasonics. In this paper, a new measurement and analysis technique for estimating the surface density as a function of frequency for a nonporous membrane or foil is introduced. This new, broadband technique is derived from the Thompson-Gray measurement model which can be simplified to the fluid layer transfer function commonly used in acoustics. The fluid layer transfer function can be further simplified to the limp-wall mass law for acoustically ‘thin’ membranes whose thickness is much less than a wavelength. The transfer function of the membrane can be efficiently measured with commercially available air-coupled ultrasonic transducers from which the surface density can be computed. Surface density estimates are presented for four membrane-like materials: aluminum foil, brass shim, polyester and polyethylene sheets.

9:10 AM

An Approach for Defect Visualization and Identification in Composite Plate Structures Using Air-Coupled Guided Ultrasound

---Rabi Sankar Panda, Prabhu Rajagopal, and **Krishnan Balasubramaniam**, Indian Institute of Technology, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

---Composite materials are today widely used in engineering applications because of superior strength-weight ratios offered by them as well as high structural performance and corrosion resistance. However defects such as fiber breakage, matrix cracking, de-bonding and delaminations in composites impact their structural integrity and reliability negatively and NDE techniques to rapidly identify such defects are valuable. Ultrasonic guided waves have over the years emerged as attractive tools for scanning of large structures and recently they have been considered for rapid inspection of plate and pipe installations. Air-coupled ultrasound for generation of Lamb waves is particularly attractive for composite applications in view of the non-contact inspection offered, as well as the possibilities for rapid mechanized scanning. In this paper we present damage identification and visualization approaches for quasi-isotropic composite plate structures, based on air-coupled plate guided ultrasonic (Lamb) waves. In the implementation demonstrated, an 8-layered quasi-isotropic [0/+45/-45/90]s Glass fiber/Epoxy laminated composite plate is interrogated using air-coupled pitch-catch guided ultrasound. Propagation of Lamb waves in the laminates and their interaction with delaminations of different sizes at various locations along the structure are studied using 3D finite element (FE) analysis. The visualization approach is validated using experiments, leading to quantitative predictions of defect parameters such as sizing, location and depth. The approach is also extended for the inspection of complex composite structural features such as I- and T-sections.

9:30 AM

Crack Investigation in the Far-Field of Laser Generated Surface Waves
---Wei Wang, Zheng Zhong, and **Yongdong Pan**, School of Aerospace Engineering and Applied Mechanics, Tongji University, 100 Zhangwu Road, Shanghai 200092, China (PRC)

---The finite element method is applied to simulate the surface breaking crack interaction of laser-generated Rayleigh waves in the far field. The numerical results demonstrate that the mode-converted wave and reflected wave can be separated in the far field of the laser source, which may help the analysis of the crack interaction. According to this finding, the wave interactions to the front and back of the crack were studied in details, and Huygens principle is further employed to interpret the possible interaction features among the reflected signal. The difference in the arrival time of the reflected surface wave is linearly related to the depth and width of the crack, and it is more sensitive to the depth than width. Finally laser ultrasonic experiments were carried out to validate the numerical results, and potential technique is also investigated to quantify the crack.

9:50 AM

Equivalent Body-Force Model for Magnetostrictive Transduction In EMATS
---Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221; **Remo Ribichini**, GE Oil & Gas, TMS Service Engineering, Firenze, 50127, Italy

---Electromagnetic Acoustic Transducers (EMATs) are an attractive alternative to standard piezoelectric probes in those applications where couplant fluid cannot be used, i.e. high speed or high temperature testing, or when specific wave-modes have to be excited. When used on ferromagnetic samples, EMATs generate elastic waves through three different transduction mechanisms: the Lorentz force, the magnetization force and magnetostriction. The modelling of such phenomena has drawn the attention of several researchers, leading to different physical formalizations, especially for magnetostriction, being the most complex mechanism. This work presents a physics-based model for tangential bias field magnetostrictive EMATs employing surface tractions equivalent to the inertia body forces caused by magnetostrictive strains. This type of modelling had been previously used to validate a Finite Element models for normal bias field EMATs and here is extended to the tangential bias field configuration. Moreover, it is shown that the proposed model is equivalent to a recently developed method using the spatial convolution integral of body forces with Green's tensor to model elastic wave generation in a solid half-space.

10:30 AM

Virtual Environment Assessment for Laser-Based Vision Surface Profiling
---**Adnane O. ElSoussi**, Abed ElRahman K. Al Alami, and Bassam A. Abu-Nabah, American University of Sharjah, Department of Mechanical Engineering, Sharjah, United Arab Emirates

---Oil and gas businesses have been raising the demand from original equipment manufacturers (OEMs) to implement a reliable metrology method in assessing surface profiles of welds before and after grinding. This certainly mandates the deviation from the commonly used surface measurement gauges, which are not only operator dependent, but also limited to discrete measurements along the weld. Due to its potential accuracy and speed, the use of laser-based vision surface profiling systems have been progressively rising as part of manufacturing quality control. This effort presents a virtual environment that lends itself for developing and evaluating existing laser vision sensor (LVS) calibration and measurement techniques. A combination of two known calibration techniques is implemented to deliver a calibrated LVS system. System calibration is implemented virtually and experimentally to scan simulated and 3D printed features of known profiles, respectively. Scanned data is inverted and compared with the input profiles to validate the virtual environment capability for LVS surface profiling and preliminary assess the measurement technique for weld profiling applications. Moreover, this effort brings 3D scanning capability a step closer towards robust quality control applications in a manufacturing environment.

10:50 AM

Image Mosaicing for Automated Pipe Scanning
---**Rahul Summan**, Gordon I. Dobie, Francesco Guarato, Charles N. MacLeod, Stephen Marshall, and S. Gareth Pierce, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, 204 George Street, Glasgow G1 1XW, United Kingdom; Cailean Forrester, Inspectahire Instrument Company Ltd, Aberdeen, United Kingdom

---Remote visual inspection (RVI) is critical for the inspection of the interior condition of pipelines particularly in the nuclear, oil and gas industries. Conventional RVI equipment produces a video which is analyzed online by a trained inspector employing expert knowledge. Due to the potentially disorientating nature of the footage, this is a time intensive and error prone activity. In this paper a new probe for such visual inspections is presented. The device employs a catadioptric lens coupled with feature based structure from motion to create a 3D model of the interior surface of a pipeline. Reliance upon the availability of image features is mitigated through orientation and distance estimates from an inertial measurement unit and encoder respectively. Such a model affords a global view of the data thus permitting a greater appreciation of the nature and extent of defects. Furthermore, the technique estimates the 3D position and orientation of the probe thus providing information to direct remedial action. Results are presented for both synthetic and real pipe sections. The former enables the accuracy of the generated model to be assessed while the latter demonstrates the efficacy of the technique in a practice.

11:10 AM

Ultrasonic Near-Field Optical Microscopy using a Plasmonic Nanofocusing Probe
---**Oluwaseyi Balogun** and Xiang Chen, Department of Mechanical Engineering, Northwestern University, 2137 N. Tech Drive, Evanston, IL 60208

---Acoustic microscopy techniques enable local mapping of elastic properties and defects in solids in a nondestructive fashion. The spatial resolution of these techniques depends on the acoustic wavelength and size of the acoustic wave probe. High frequency acoustic waves with nanoscale wavelengths can be generated with ultrafast lasers. However, detection of acoustic waves with a nanoscale probe is more challenging to achieve due to the classical diffraction limit. In order to enable acoustic microscopy with nanoscale spatial resolution, we developed an ultrasonic near-field optical microscopy technique (UNOM) that uses a near-field optical probe for local detection of ultrasound. In pure optical microscopy applications, a near-field optical probe allows for formation of optical images with a lateral spatial resolution that is beyond the diffraction limit. In order to overcome the low intensity of the near-field optical probe, which limits the ultrasound detection sensitivity, we enhance the intensity by coupling light to surface Plasmon polaritons (SPPs). In the UNOM, free space light is coupled to propagating SPPs on the shaft of an atomic force microscope (AFM) probe. The SPPs travel adiabatically down the AFM shaft and couple to localized plasmons at the probe tip, where a bright nanoscale light source is produced. Experimental results would be presented that demonstrate the application of the UNOM technique for local time resolved measurement of pulsed laser generated ultrasound, local mapping of elastic properties, and detection of defects in the acoustic near-field.

11:30 AM

Non-Destructive Evaluation by Digital Volumetric Speckle Photography (DVSP) Method

---**H. Sam Huang** and Fu-Pen Chiang, Department of Mechanical Engineering, Stonybrook University, Stonybrook, NY 11794

---Accurate description of the strain field under loading permits evaluation of stress field, which is crucial to predicting progressive failure of a structure. The digital image correlation (DIC) method has been used for the measurement of the full field in-plane displacement for 2D problems [1-2] and in-plane, out-of-plane displacement for 3D problems [3]. Recently, with advances of Computed Tomography (CT) scanning, DIC method has been extended to calculate strain fields inside the rock [4]. Unlike the methods in [1-3] that can only evaluate the state of a structure on the surface, this so called volumetric speckle photography technique has the advantage of fully investigating the strain state inside the objects. Unlike the ultrasonic method that can only be used in on macroscopic scale materials due to the limitation of available sizes of the transducers, Volumetric Speckle Photography method can be applied to different size of structures depending on the images obtained from CT machines or micro CT machines. In this research, we will present the numerical test on the reliability of the Volumetric Speckle Photography we developed.

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Session 11

SESSION 11
STUDENT POSTER COMPETITION
Hawk

NOTE: Student posters are to be displayed in Hawk on Monday, July 21st, from 3:00 to 6:00 p.m. for evening judging ONLY-not for public display. The posters will be open for public viewing during the regular Poster Session 11 on Tuesday, July 22nd, from 1:30-3:10 p.m. For more details on the student poster competition, please see the "Conference Guide" document on the QNDE web site at: http://www.qndeprograms.org/2014/

Omni-Directional Shear-Horizontal Wave Magnetostrictive Patch Transducer for the Inspection of a Ferromagnetic Plate
---**Hong Min Seung** and Yoon Young Kim, Seoul National Univeristy, School of Mech./Aerospace Eng. Seoul, Republic of Korea

Fully Contactless Ultrasonic System to Characterized Concrete Structure with Guided Wave Approach and Energy Attenuation
---**Suyun Ham** and John S. Popovics, The University of Illinois, Urbana-Champaign, Civil and Env. Eng., Urbana, IL 61874

Analysis of Critically Refracted Longitudinal Waves
---**Ning Pei** and Leonard J. Bond, Iowa State University, Center for Nondestructive Evaluation, Ames, IA 50011-3041

MUSIC Imaging Method for Low-High Frequency Inspection of Composite Multi-Layers
---**Giacomo Rodeghiero**, Ping-Ping Ding, Marc Lambert, and Dominique Lesselier, Département de Recherche en Electromagnétisme – Laboratoire des Signaux et Systèmes UMR8506 CNRS-SUPELEC-Univ. Paris Sud, 3 rue Joliot-Curie, 91192 Gif-sur-Yvette, France; Yu Zhong, A*STAR, Institution of High Performance Computing, 138632 Singapore

Sub-Sea Radiography of Pipelines Using Limited Projections
---**Misty I. Haith**, Peter E. Huthwaite, and Michael J. S. Lowe, Imperial College London, ME Department, London, UK

Effect of Surface Unevenness on Non-Contact Surface Wave Measurements Using a Rolling Microphone Array
---**Henrik Bjurström** and Nils Ryden, KTH Royal Institute of Technology, Highway and Railway Eng., 100 44 Stockholm, Sweden

Eddy-Current Array Sensitivity
---**Robert R. Hughes** and Steve M. Dixon, Dept. of Physics, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL, UK

Single-Mode Omni-Directional Lamb Wave Generation by Magnetostrictive and Electromagnetic Acoustic Transducers
---**Joo Kyung Lee** and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Eng., Republic of Korea

Detection and Characterization of Impact Damage in Composite Panels using Multiple Ultrasonic Methods
---**Westin B. Williams,** Thomas E. Michaels, and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

Stress-Dependent Attenuation in Polycrystals: Theory and Experiment
---**Andrea Arguelles**, Christopher M. Kube, and Joseph A. Turner, University of Nebraska, Mech./Materials Engineering, NE 68588

A 2D Finite Element Simulation of a High Temperature Liquid-Coupled Ultrasonic NDT System
---**Prathamesh Bilgunde** and Leonard J. Bond, Center for NDE and Dept. Aero. Engineering, Iowa State University, Ames IA 50011

Economics of On-line Monitoring of Wind Turbines: Cost Benefit Analysis
---**Jeremy Van Dam**[1] and Leonard J. Bond[1,2], Center for NDE, and [1]Mechanical Engineering Department; [2]Aero. Engineering Department, Iowa State University, Ames IA 50011

Second Harmonic Generation Using Nonlinear Rayleigh Surface Waves in Stone
---**Margaret M. Smith**, Gun Kim, Jin-Yeon Kim, Kimberly E. Kurtis, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355; Laurence J. Jacobs, Georgia Institute of Technology, GW Woodruff School of Mechanical Engineering, Atlanta, GA 30332

3D Finite Element Modeling of Lamb Wave Scattering from a Sessile Water Droplet
---**Hongye Liu** and Cunfu He, Beijing University of Technology, College of Mechanical Engineering and Applied Electronics Technology, Beijing, PR China; Jennifer E. Michaels, Xin Chen, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

Development of Subharmonic Phased Array Using Surface Acoustic Wave for Measurement of Closed Crack Length
---**Akihiro Ohuchi**, Hiroshi Yorifuji, Kentaro Jinno, Azusa Sugawara, Yoshikazu Ohara, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

A Fast Integral Equation Model With a Dedicated Green's Kernel for Eddy-Current Inspection of Fastener Holes in Driver Pickup Mode
---**Konstantinos Pipis** and Anastassios Skarlatos, CEA, LIST, Département Imagerie Simulation pour le Contrôle, France; Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani, Greece; Dominique Lesselier, Laboratoire des Signaux et Systèmes, Département de Recherche en Electromagnétisme, UMR8506 (CNRS-SUPELEC-U. Paris Sud), Gif-sur-Yvette Cedex, France

A Study on Closed Form Solution of Guided waves Scattering Amplitude by the Use of Reciprocity Theorem in the Cylindrical Coordinates
---**Jaesun Lee** and Younho Cho, School of Mechanical Engineering, Pusan National University, Pusan, South Korea; Jan D. Achenbach, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

Evaluation of Material Microstructure Changes in High Speed Tool Steel by the Non-Collinear Wave Mixing Technique with MST(Magnetostrictive Transducer)
---Dong Jin Lee, **Jeongseok Choi**, and Younho Cho, Pusan National University, School of Mechanical Engineering, busandaehak-ro 63 beon-gil, Geumjeong-gu, Pusan, 609-735, South Korea

A Study on Laser-based Ultrasonic Technique by the Use of Guided Wave Tomographic Imaging
---**Junpil Park**, Juyoung Lim, and Younho Cho, School of Mechanical Engineering, Pusan National University, Pusan, South Korea; Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL, 60208

Thickness Measurements of Sub-Millimetre Thickness Foils Using Lamb Wave Dispersion
---**Kevin L. McAughey**, Rachel S. Edwards, and Steve Dixon, Department of Physics, University of Warwick, Coventry, CV4 7AL, UK; Kevin L. McAughey and Mark D. G. Potter, Sonemat Ltd., The Venture Centre, Coventry, CV4 7EZ, UK

A Probabilistic Approach to Automatic Registration of NDE Image Data to a 3D Specimen Model
---**Elizabeth D. Gregory** and Stephen D. Holland, Iowa State University, Dept. of Aero. Eng. Center for NDE, Ames, IA 50011

Vibrational Modes of Thin Plates and Their Application to Flexural Ultrasound Transducers
---**Tobias Eriksson**, Steve Dixon, and S. N. Ramadas, University of Warwick, Department of Physics, Coventry, CV4 7AL, UK

Detectability Limitations With 3-D Point Reconstruction Algorithms Using Digital Radiography
---**Erik Lindgren,** Dept. of Materials and Mfg. Technology, Chalmers University of Technology, 412 96 Göteborg, Sweden

Pseudo-Coloring for Ultrasonic NDE
---**Anton Van Pamel** and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Colin Brett, E.ON Technologies (Ratcliffe) Limited Technology Centre, Ratcliffe-on-Soar, Nottinghamshire, United Kingdom

SESSION 11 – POSTERS
GUIDED WAVES, SURFACE WAVES, FUNDAMENTALS, NDE SENSORS AND SYSTEMS

Guided Waves

Assessment of Ultrasonic NDT Methods for Highspeed Rail Inspection
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PZT Guided Waves Sensor Permanently Attached on Multi-Wire AGW12 Cables Used as Communication Medium
---Gianpiero Trane[1] and **Rito Mijarez**[1], [1]Instituto de Investigaciones Eléctricas, Gerencia de Control, Electrónica y Comunicaciones, Calle Reforma 113, Col. Palmira, C.P. 62490, Cuernavaca, Morelos, Mexico; Arturo Baltazar[2], [2]Centro de Investigación y Estudios Avanzados del IPN, Unidad Saltillo Carretera Saltillo-Monterrey Km 13.5, C.P. 25900 Ramos Arizpe, Coahuila, México

Field Trials Results of Guided Wave Tomography
---**Arno Volker** and Tim van Zon, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek or TNO (Netherlands Organisation for Applied Scientific Research), Stieltjesweg 1, 2600 AD Delft, The Netherlands; Edwin van der Leden, CIT Industrial services b.v.

Multimode Dispersion Compensated Pulse-Echo Guided Wave Inspection
---**R. Roberts**, D. Chimenti, and E. Peters, Iowa State University, Center for NDE, Ames IA 50011

Surface Waves

Study on Thickness Measurement of Nickel Thin Film Using Dispersion Characteristic of Surface Wave Velocity
---**Taesung Park**, Byngseok Cho, and Ikkeun Park, Seoul National University of Science and Technology, Mechanical & Automotive Engineering, Seoul, Korea; Miso Kim and Seungseok Lee, Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea

Quantitative Diagnostics of Multilayered Composite Structures with Ultrasonic Guided Waves
---**G. Bunget**[1], F.J. Friedersdorf[1], and J. K. Na[2], [1]Luna Innovations Inc., Roanoke, VA 24016; [2]Edison Welding Institute, Columbus, OH 43221

Fundamentals

Photoelastic Visualization of SV Wave Propagation and Scattering
---**Zhiwu An**, Shijie Jin, Guoxuan Lian, Xiaomin Wang, Institute of Acoustics, Chinese Academy of Sciences, No. 21, Bei-Si-Huan-Xi Road, Haidian District, Beijing 100190, China (PRC)

Research on Ultrasonic Guided Waves Propagating in Pipes Embedded in Infinite Media Based on SAFE-IFE Method
---**Xiaowei Zhang**, L.V. Fuzai, Pengfei Zhang, and Jianhong Hu, Institute of Modern Manufacture Engineering, Hangzhou, Zhejiang Province, China; Zhifeng Tang, Institute of Advanced Digital Technologies and Instrumentation, Hangzhou, Zhejiang Province, China

Fatigue Crack Detection Using Subharmonic Component with Nonlinear Boundary Conditions
---Weiliang Wu, Wenzhong Qu, and Li Xiao, Wuhan University, Department of Engineering Mechanics, Wuhan, Hubei, China; **Yanfeng Shen** and Victor Giurgiutiu, University of South Carolina, Department of Mechanical Engineering, Columbia, SC 29201

Simulation of the Second Harmonic Generation in Reflected Modes
---**Anne Romer**, Jin-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30318

Curved Surface Energy Coefficients Integration Echo Energy Estimation Method for Pipe Inner Surface Longitudinal Crack Detection When Using Mode-Transformed Compression Wave Adaptation of Shear Wave Testing
---**Shiyuan Zhou**, Haoyu Sun, Chunguang Xu, Xiandong Cao, and Dingguo Xiao, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, China

Subharmonic Resonance Caused by Contact Acoustic Nonlinearity
---**Yuji Kato**, Hirotaka Tanaka, Tatsuhiro Okamoto, and Toshihiko Sugiura, Keio University, Dept. of Mechanical Engineering, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama-shi, Kanagawa 223-8522

Simulation of Time Reversal Beam Fields with Contacting Nonlinear Interfaces and Imaging of Crack-Like Microdamage
---**Hyunjo Jeong**, Sunjong Cho, and Kiwoong Nam, Wonkwang University, Mechanical and Automotive Engineering, Iksan, Jonbuk, Korea

Sensitivity Comparison of Relative Acoustic Nonlinear Parameter Measurement by Thermal Aging
---**Hogeon Seo**, Gang Ren, and Jongbeom Kim, Hanyang University, Department of Mechanical Convergence Engineering, Seoul, Korea; Kyung-Young Jhang, Hanyang University, School of Mechanical Engineering, Seoul, Korea

NDE Sensors and Systems

Development of Training Modules for Magnetic Particle Inspection
---Daigo Kosaka[1], **David J. Eisenmann**[1], Darrel Enyart[1], Norio Nakagawa[1], and Chester Lo[2], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]501 Murphy Ranch Road, Apt. 314, Milpitas, CA 95035

Measurement of Ultrasonic Nonlinear Parameter Using Acoustic Buffer and Laser Doppler Vibrometer
---**Dae-Cheol Seo**, Seung Hyun Cho, Chun-Su Park, and Seung-Suk Lee, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea

Measurement and Fitting Techniques for the Assessment of Material Nonlinearity with Air-Coupled Piezoelectric Receivers Using Nonlinear Rayleigh Waves
---**David E. Torello** and Laurence J. Jacobs, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332; Jin-Yeon Kim and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 30332; Jianmin Qu, Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208

3:10 PM ***Break***

Omni-Directional Shear-Horizontal Wave Magnetostrictive Patch Transducer for the Inspection of a Ferromagnetic Plate

---**Hong Min Seung** and Yoon Young Kim, Seoul National Univeristy, School of Mechanical and Aerospace Engineering, Seoul, Republic of Korea

---This study presents our efforts to investigate if omni-directional shear-horizontal waves can be generated with a magnetostrictive patch transducer in a ferromagnetic plate. The transducer consists of a thin magnetostrictive patch to be bonded onto a test plate, a toroidal coil wound over the patch and a cylindrical permanent magnet and it was shown to be useful for the generation of omni-directional shear-horizontal waves in a non-ferromagnetic plate. However, its use in ferromagnetic plates, due to significant magnetic flux leakage into a ferromagnetic plate and the simultaneous generation of unwanted wave modes, has not been realized or implemented. To overcome these difficulties, we propose a technique to minimize the leakage. In this technique, some gap is intentionally inserted between a magnetostrictive patch and a test ferromagnetic plate by installing a bonding layer of a properly-selected thickness. If the thickness is optimally selected, the magnetic flux leakage into the ferromagnetic plate is minimized and the magnetic field will be mainly supplied to the magnetostrictive patch of the transducer. If the thickness of the bonding layer approaches zero, on the other hand, not only the magnetostrictive patch but also the test ferromagnetic plate would be simultaneously excited, causing additional generation of unwanted Lamb wave modes. An optimal bonding thickness was determined by numerical simulations. In addition, the optimal vertical location of a permanent magnet was found. Finally, a set of experiments were performed to check the effectiveness of the proposed technique. To facilitate the experiments, a special housing was fabricated to adjust the thickness of the bonding layer accurately.---This research was supported by the National Research Foundation of Korea (NRF) grant (No. 2013-035194) funded by the Korean Ministry of Education, Science and Technology (MEST) contracted through IAMD at Seoul National University and the Brain Korea 21 Plus Project in 2014.

Fully Contactless Ultrasonic System to Characterized Concrete Structure with Guided Wave Approach and Energy Attenuation

---**Suyun Ham** and John S. Popovics, The University of Illinois, Urbana-Champaign, Civil and Environmental Engineering, Urbana, IL 61874

---Ultrasonic techniques provide an effective non-destructive evaluation (NDE) method to monitor concrete structures, but the need to perform rapid and accurate interpretation assessment requires evaluation of hundreds, or even thousands, of measurement data. Use of a fully contactless ultrasonic system can save time and labor through rapid implementation, and can enable automated and controlled data acquisition for example through robotic scanning. The fully contactless ultrasonic system consists of both air-coupled electrostatic transducer and air-coupled MEMS sensor. This paper describes our efforts to develop contactless surface wave system for NDE of concrete in structures. The developed contactless sensors, controlled scanning system with mobile apparatus and employed signal processing scheme are described. Our fully contactless system is used for detecting delaminations with guided wave approach and characterizing the level of microcracked concrete with energy attenuation. The concrete delamination are interpreted in terms of guided plate wave (Lamb wave) theory carried out on full-scale concrete slabs. They are formed by coupled longitudinal and transverse wave motion and include an infinite number of individual symmetrical (S) and anti-symmetric (A) solution modes. Each Lamb mode has a distinct phase velocity, which unlike the body and surface waves, is dispersive (i.e. is a function of frequency). Also, energy loss (attenuation) is a good indicator of distributed cracks in concrete. Therefore, our ultrasonic system showed a sensitive detector of delamination and level of microcracking in concrete providing many consistent data.

Analysis of Critically Refracted Longitudinal Waves

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---Fabrication processes, such as, welding, forging, and rolling can induce residual stress in metals that will impact product performance and phenomena such as cracking and corrosion. To better manage residual stress tools are needed to map their distribution. The critically refracted ultrasonic longitudinal (LCR) wave is one approach that has been used for residual stress characterization.[1-3] It has been shown to be sensitive to stress and less sensitive to the effects of the texture of the material. Although LCR is increasingly widely applied, the factors that influence the LCR beam are seldom discussed. This paper reports a numerical model used to investigate the transducers' parameters that can contribute to the directionality of LCR to enable performance optimization for industrial applications. An orthogonal test method[4] is used to study transducer parameters which influences LCR beams. This method is a design tool used to study and optimize multiple parameter experiments and it can identify which parameter or parameters are of most significance. The simulation of the sound field in a 2-D "water-steel" model is obtained using a Spatial Fourier Analysis method[5]. The effects of incident angle, the aperture and the center frequency of the transducer were studied. Results show that the aperture and the center frequency of the transducer appear to be the most important factors in controlling the directivity of LCR wave fields.

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MUSIC Imaging Method for Low-High Frequency Inspection of Composite Multi-Layers

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---Non-destructive Testing-Evaluation (NdT-E) of damaged multi-layer structures like fiber-made composite materials involved in aeronautic and automotive industries is a topic of great interest to solve problems of viability and security. From eddy currents to test graphite-based materials to microwaves and beyond to test glass-based composite structures, one aims to obtain images of the possibly damaged parts with robust, fast inversion algorithms. In this contribution, such algorithms are tailored to detect small (compared to the local wavelength in propagative regime or skin depth in diffusive regime) inclusions affecting the structures mentioned above. These inclusions may be voids, fluid-filled cavities (i.e., isotropic) or even uniaxial ones. Yet this requires proper models of the layerings to compute their response due to electromagnetic sources, notably electric dipoles or magnetic coils. Based on [1-2], it is proposed herein a method to compute in an effective fashion the dyadic Green's functions (DGF) for such structures within the framework of contrast-source integral equations. Special care is taken when the sources are far away from the origin, yielding an oscillating spectrum of the DGF. The Multiple Signal Classification (MUSIC) imaging method [3], which uses such DGF, is applied to find the position of small defects. Possible application of MUSIC for structure delaminations is treated also.

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Sub-Sea Radiography of Pipelines Using Limited Projections

---**Misty I. Haith**, Peter E. Huthwaite, and Michael J. S. Lowe, Imperial College London, Mechanical Engineering Department, London, United Kingdom

---Accurate and reliable detection of subsea pipeline corrosion is very important in order to identify potential leakage sites. However, due to the traditional use of film in industrial radiography there are relatively few methods of image processing and combination suited to subsea pipeline inspection. Multiple radiographs are often taken at different angles around the pipe to obtain full coverage, but these are examined individually. Combining multiple projections could add additional information such as defect depth, and may also increase image quality in the overlapping edge regions of the images. This work presents a novel method of stitching multiple radiographs into a single image showing the full pipe circumference. A background subtraction technique is first used to separate defects from background intensity changes in two images at different angles, with a common defect visible in both. The two images are overlaid and the optimum overlap calculated through error minimization. The method is tested on simulated data and its effect on image quality examined.

Effect of Surface Unevenness on Non-Contact Surface Wave Measurements Using a Rolling Microphone Array

---**Henrik Bjurström** and Nils Ryden, KTH Royal Institute of Technology, Highway and Railway Engineering, 100 44 Stockholm, Sweden

---Material characterization by non-destructive seismic testing using a rolling multichannel microphone array is today an attractive alternative to more conventional accelerometer testing. Non-contact measurements are faster and therefore less expensive. This study presents surface wave data collected from a concrete plate using a multichannel rolling microphone array. Results show that surface roughness and unevenness can have a major effect on the measured phase velocities. Equal distances between the surface and each microphone in the array are crucial to receive correct data. A relatively small misalignment between the surface and the microphone array is enough to cause large errors in the calculations of phase velocities and subsequent material parameters. Different measures to overcome these problems are discussed in this study. An attempt to neutralize the misalignments is presented where the data acquisition trolley is rolled along a straight line twice in opposite directions in order to even out the misalignments. The study shows that multiple impacts from opposite sides of the microphone array have the potential of correcting the problem under certain circumstances.---The Swedish transport administration (Trafikverket) and the Swedish construction industry's organization for research and development (SBUF) are acknowledged for their financial support.

Eddy-Current Array Sensitivity

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---The use of eddy-current array (ECA) technology for non-destructive crack detection is rapidly growing within industry, however, superalloys used for fracture critical components often have low conductivities which can mean conventional inspections are insensitive to the smallest target defects. The sensitivity and suitability of ECA configurations and techniques for the inspection of such components was investigated. A number of characterization experiments, including probability of detection and defect signal variation across arrays, were performed on selected commercially available array probes. The results identify the benefits and limitations of arrays, certain measurement modes and probe designs for defect detection in aerospace superalloys. The findings of this investigation can be used to assist in the design and operation of future ECA probes and systems geared at the aerospace industry.

Single-Mode Omni-Directional Lamb Wave Generation by Magnetostrictive and Electromagnetic Acoustic Transducers

---**Joo Kyung Lee** and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Republic of Korea

---Successful transductions of omni-directional Lamb waves by axisymmetric magnetostrictive patch (MPT) and electromagnetic acoustic (EMAT) transducers have been recently reported, but single-mode transduction still remains to be resolved. For instance, an A0 mode Lamb wave is often accompanied by an S0 mode Lamb wave even if only the former is desired. For wave excitation and measurement, these transducers use single planar spiral coils (PSC's) to which time-varying electric current is sent. While the configurations of these transducers determine the wavelengths of the dominant wave modes, it is not possible to excite only the desired single wave mode among possible multiple modes. Our proposition is to use double PSC's and send electric currents of opposite directions. Equivalently, one can simply wind one PSC clockwise and the other, counterclockwise with a current of the same direction. In selecting the desired wave mode and rejecting undesired wave modes for a selected frequency, the mean radii of the two PSC's must be properly selected among others. This study reveals that a set of double PSC's must be differently sized for single-mode transduction with MPT's and EMAT's. The physics behind this finding was explained theoretically and numerically. For experimental verification, we aimed to reject the A0 modes while selecting the S0 modes at selected frequencies. The experimental results conducted with EMAT's and MPT's confirmed the effectiveness of the proposed single-mode transduction approach using double PSC's.

Detection and Characterization of Impact Damage in Composite Panels using Multiple Ultrasonic Methods

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---Abrupt impacts to solid laminate composite panels often produce internal damage that is not visible on the impacted surface. It is important that such damage be promptly detected since it can compromise the strength of composite structures. Ultrasonic C-scan imaging has been extensively used to detect and characterize impact damage using both pulse-echo and through-transmission methods. More recently developed guided wave based imaging methods, such as acoustic wavefield imaging and sparse array imaging with baseline subtraction, have also been used to successfully detect damage in composite panels; however, their performance is generally not comparable to that achieved with bulk wave C-scans. For this study, various force impacts were used to create defect conditions ranging from barely detectable damage to extensive damage that was visible on the impact surface. Guided wave signals were recorded from an attached sparse transducer array before and after the impacts, and panels were scanned using both conventional ultrasonic C-scan methods and acoustic wavefield imaging. For each method, imaging results are compared to determine the detectable damage thresholds and accuracy of determining defect areas.

Stress-Dependent Attenuation in Polycrystals: Theory and Experiment

---**Andrea Arguelles**, Christopher M. Kube, and Joseph A. Turner, University of Nebraska, Mechanical and Materials Engineering, NE 68588

---Acoustoelasticity theory traditionally describes the phase velocity of a wave propagating in a stressed medium. The stress-dependent phase velocity is defined through the real components of the wave number solutions of the governing Christoffel equations. The imaginary or dissipative part of the wave number defines the attenuation and is often disregarded in many acoustoelastic applications. However, recent research has been focused on the theoretical ultrasonic attenuation of a stressed polycrystal. This presentation reviews those theoretical foundations and presents experimental attenuation measurements of longitudinal and shear waves in a steel bar as a function of tensile stress. Various combinations of propagation and polarization directions with respect to the uniaxial loading direction are explored. The attenuation is proven to be more sensitive to the applied stress than traditional wave speed techniques. The increased sensitivity is due to the second-order elastic grain statistics present during scattering events. Practical experimental configurations for stress measurement applications based on scattering and attenuation are discussed.

A 2D Finite Element Simulation of a High Temperature Liquid-Coupled Ultrasonic NDT System

---**Prathamesh Bilgunde** and Leonard J. Bond, Center for NDE and Department of Aerospace Engineering, Iowa State University, Ames IA 50011

---A pulse-echo ultrasonic non-destructive testing (NDT) system using longitudinal waves in high temperature liquid medium (liquid metal or a molten salt) is proposed for inspection in advanced small modular reactors [1, 2]. Performing experiments in a molten salt or liquid metal at temperature (~250C) is both experimentally challenging and expensive. To provide greater insight into the transducer performance and to reduce the cost of experimental verification a modeling approach was adopted. The model will initially be validated with room temperature experiments. To enable performance to be optimized a finite element (FE) model is being developed that represents operation of a single element ultrasonic transducer system in liquid coolant in an axisymmetric two dimensions form. The two dimensional geometry is divided into sub-domains which are defined by governing equations for corresponding solid and liquid sections. To reduce the number of degrees of freedom for the system, a separate routine is implemented for defining absorbing regions. An iterative model study is performed to determine subdomain dependent element size for meshing by comparing the pressure amplitude of responses and the convergence time of solutions. The finite element model incorporates random noise to model thermal and electro-magnetic interference which can be problematic in nuclear reactors at high temperature. Initial numerical predictions of the two dimensional model have been successfully validated at room temperature with experimental data for a simple aluminum and steel plate with a finite through-thickness hole in liquid coolants. The model is being developed to incorporate additional complexity and ranges of properties, including operation at elevated temperature.---The work is funded by the U.S. Department of Energy's office of Nuclear Energy under Nuclear Energy University (NEUP) programs. The authors would like to acknowledge generous support of the U.S. Department of Energy.

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Economics of On-line Monitoring of Wind Turbines: Cost Benefit Analysis
---**Jeremy Van Dam**[1] and Leonard J. Bond[1,2], Center for Nondestructive Evaluation, and [1]Mechanical Engineering Department; [2]Aerospace Engineering Department, Iowa State University, Ames IA 50011

---Operations and maintenance (O&M) costs are found to easily have an average share over the lifetime of the turbine of approximately 20%-25% of total levelized cost per kWh produced. Monitoring and then condition based maintenance (CBM) of wind turbine blades has the potential to reduce O&M costs and hence reduce the overall cost of wind energy, for example by simply reducing, or even eliminating, the need of sending maintenance personnel to remote locations to examine increasingly longer blades. This paper will report a cost benefit analysis which will examine whether or not the added costs associated with structural health monitoring (SHM) systems will be economic. SHM and condition based maintenance offers the potential to decrease the overall cost of electricity for wind energy by performing inspections only when a problem is highlighted and hence reducing the number of physical inspections, using monitoring to reduce the potential for missed significant defects, and catastrophic failures. Current methods of inspection include yearly physical examinations in which technicians must either repel down the blades or be supported by a platform attached to the outside of the tower. An SHM system will reduce the need for these physical inspections, and have them occur when an issue is highlighted and hence enable defects to be detected before failures occur. In the economics failures and unplanned outages can cause significant downtime, particularly when waiting for major parts and all these events give added repair costs. SHM offers a method for reducing costs. Before the industry will adopt advanced SHM the cost-benefit-analysis needs to show that systems on wind turbine blades gives an appropriate, return on the investment.---The research reported in the paper has been supported by the National Science Foundation Integrative Graduate Education and Research Traineeship (IGERT) award in Wind Energy Science, Engineering and Policy (WESEP), at Iowa State University.

Second Harmonic Generation Using Nonlinear Rayleigh Surface Waves in Stone
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---This research tests the potential application of the Second Harmonic Generation (SHG) method using nonlinear Rayleigh surface waves to nondestructively quantify surface microstructural changes in thin stone. The acoustic nonlinearity parameter (β) has been assessed as a meaningful indicator for characterizing the nonlinearity of civil engineering materials; additionally, Rayleigh waves offer the opportunity to isolate a material's near surface microstructural status. Sandstone was selected for testing due to its relative uniformity and small grain size compared to other stone types; the sample thickness was 2 inches to reflect the minimum panel thickness recommended by the Indiana Limestone Institute1. For this research, initially fully non-contact generation and detection techniques are evaluated before a 100 kHz wedge transmitter and a 200 kHz air-coupled receiver are employed for generation and detection of nonlinear Rayleigh wave. Non-contact transmitters and receivers have advantages such as removing the irregularities associated with coupling as well as not leaving residues which in stone applications can be considered aesthetically damaging. The experimental results show that the nonlinear parameter (β) can be effectively isolated using the wedge transmitter and non-contact set up and that too much of the signal strength is lost in the fully non-contact method to extract meaningful results for this stone and stones with slow wave speeds. This indicates that the proposed SHG technique is effective for evaluating the nonlinearity parameter (β) and can next be applied to characterize near surface microstructural changes in thin applications of dimension stone.

3D Finite Element Modeling of Lamb Wave Scattering from a Sessile Water Droplet

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---The interaction between Lamb waves and a sessile water droplet (i.e., a droplet resting on a horizontal surface) is highly complex and limited research has addressed this issue. Recently, simulations were performed on the similar interaction of surface waves with a water droplet. Motivated by these results, this current work applies 3D finite element modeling to study far-field scattering of the fundamental antisymmetric Lamb wave mode from a single, axisymmetric water droplet on an aluminum plate. The profile of the droplet, which is affected by gravity, surface tension, and its volume, determines the scattering behavior of incident Lamb waves. For small droplets, the effects of gravity can be ignored and the droplet is well-described by a spherical cap. The effects of the diameter and contact angle of this cap on far-field scattering are investigated by analyzing guided wave signals in the plate with and without the droplet. Scattered wave amplitudes expressed as a function of the scattered angle are compared for a number of different droplet geometries.---The first author (Mr. Hongye Liu) was supported by the National Natural Science Foundation of China (Grant Nos. 51235001, 11372016) and the China Scholarship Council.

Development of Subharmonic Phased Array Using Surface Acoustic Wave for Measurement of Closed Crack Length

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---Accurate measurement of crack depth and length is required for the evaluation of structures. For the crack depth measurement, we have developed an imaging method, subharmonic phased array for crack evaluation using bulk wave (Bulk SPACE) [Ohara, et al., APL (2007)], applied on the opposite side of the crack opening. For the crack length measurement, the combination of surface acoustic wave (SAW) and an array transducer is promising, applied on the crack opening side. Thus far, SAW generation by an array transducer with a wedge was proposed [Ing, et al., APL (1996)]. However, its combination with imaging and/or nonlinear ultrasound has yet to be realized. In this study, we propose SAW SPACE to measure closed crack length. An array transducer with a wedge designed to generate SAW is placed on a crack opening side. The SAW was focused following the delay law formulated assuming that the horizontal component of longitudinal wave velocity in the wedge equals to the Rayleigh wave velocity of the specimen. After filtering the received signals at fundamental and subharmonic frequencies, they are shift-summed to create fundamental array (FA) and subharmonic array (SA) images, visualizing the open and closed parts of crack, respectively. To verify it, the SAW SPACE was applied to the specimens with a fatigue crack (A7075) and a stress corrosion crack (SCC) (SUS304). As a result, the open and closed parts of crack were imaged in FA and SA images, respectively. The crack lengths measured in SA images were almost the same as the true ones. Thus it was verified that SAW SPCE is useful in measuring closed crack lengths. Furthermore, the SAW SPACE has another advantage that the interaction between ultrasounds and cracks can be directly observed by scanning a laser interferometer. As a result, we found that there were differences in SAW scattering, reflection and the transmittance between the fatigue crack and the SCC. This measurement will be useful in understanding the interaction between SAW and crack, and in improving inspection conditions.

A Fast Integral Equation Model With a Dedicated Green's Kernel for Eddy-Current Inspection of Fastener Holes in Driver Pickup Mode

---**Konstantinos Pipis** and Anastassios Skarlatos, CEA, LIST, Département Imagerie Simulation pour le Contrôle, France; Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani, Greece; Dominique Lesselier, Laboratoire des Signaux et Systèmes, Département de Recherche en Electromagnétisme, UMR8506 (CNRS-SUPELEC-U. Paris Sud), Gif-sur-Yvette cedex, France

---Eddy-current testing of airplane's fasteners is an application of central importance in the aerospace industry, which raises the need for fast and precise simulation methods. The integral equation formalism is particularly well suited for treating this problem since the discretization is restricted to the defect's surface (Surface Integral Method - SIM), in the case of a thin crack, or its volume (Volume Integral Method – VIM) in the case of volumetric defects. This formulation requires the calculation of the electric field in the absence of the flaw (primary field) as well as the Green's function expression corresponding to the geometry of the unflawed piece. State-of-the-art models based on the integral equation approach consider the borehole volume as an artificial defect, which is discretized and treated via the VIM making use of the Green's dyad of a planar multilayered medium [1],[2]. However, the discretization of the borehole may lead to increased computational times, given its relatively large dimensions, which cancels the benefits of the integral equation approach. In this contribution, the Green's kernel corresponding to a conductive plate with a borehole is calculated using the truncated region eigenfunction expansion (TREE) approach, and the derived expression is then applied to the integral equation formulation, thus restricting the application of the latter solely to the crack surface. Consequently, the solution of the appropriate integral equation using this Green's function results in a considerable solution speed-up comparing to the conventional approach cited. In addition, the construction of a dedicated Green's function allows the inspection inside the borehole and, thus, the inspection of deeper cracks. The specific inspection arrangement using a driver pick up probe will be simulated as case-study, in order to demonstrate the performance of the proposed approach.

A Study on Closed Form Solution of Guided waves Scattering Amplitude by the Use of Reciprocity Theorem in the Cylindrical Coordinates
---**Jaesun Lee** and Younho Cho, School of Mechanical Engineering, Pusan National University, Pusan, South Korea; Jan D. Achenbach, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

---The guided wave technique is well known for long range pipe inspection. Guided wave scattered signal analysis is difficult due to the complex geometry such as corrosion. Reciprocity relation is well established theorem to convert complicate mathematical expression to simpler manner. Wave signal analysis is performed for half-space and plate problems with reciprocity approach by earlier papers. The advantage of applying reciprocity theorem is providing closed form solution of scattered wave amplitude calculation. However, it is hard to find reciprocity relation application on cylindrical coordinates. In this paper, reciprocity theorem is applied on cylindrical coordinate for wave propagation pattern analysis. The wave field is obtained in an elegant manner by using a superposition technique and the reciprocity theorem for three-dimensional elastodynamics. For the scattered field, there are two elastodynamic stages; actual wave field excited by time-harmonic loading, virtual wave. The amplitudes of the propagating waves can easily be obtained with a much simpler calculation by reciprocity relation with closed form solution.

Evaluation of Material Microstructure Changes in High Speed Tool Steel by the Non-Collinear Wave Mixing Technique with MST (Magnetostrictive Transducer)
---Dong Jin Lee, **Jeongseok Choi**, and Younho Cho, Pusan National University, School of Mechanical Engineering, busandaehak-ro 63 beon-gil, Geumjeong-gu, Pusan, 609-735, South Korea

---Evaluation of material microstructure changes plays an important role in predicting material failure. Both destructive and nondestructive testings can be used to evaluate the variation of material microstructure. Destructive methods are used to directly verify the changes of material via microstructure picture in a vigorous manner while nonlinear ultrasonic NDE can render a promising tool for the cases. In this study, the MST driven non-collinear wave mixing technique is implemented to evaluate the material microstructure changes in high speed tool steel. The resonant wave is used to analyze the acoustic nonlinearity which is influenced by microstructure changes with various austenitizing temperature effects. Correlation microstructure change between the acoustic nonlinearity and material microstructure is accomplished to explore the feasibility of the non-collinear mixing technique.

A Study on Laser-based Ultrasonic Technique by the Use of Guided Wave Tomographic Imaging

---**Junpil Park**, Juyoung Lim, and Younho Cho, School of Mechanical Engineering, Pusan National University, Pusan, South Korea; Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL, 60208

---Guided wave tests are impractical for investigating specimens with limited accessibility and coarse surfaces or geometrically complicated features. A non-contact setup with a laser ultrasonic transmitter and receiver is the classic attractive for guided wave inspection. The present work was done to develop a non-contact guided-wave tomography technique by laser ultrasonic technique in a plate-like structure. A method for Lam wave generation and detection in an aluminum plate with a pulse laser ultrasonic transmitter and a Michelson interferometer receiver has been developed. In the images obtained by laser scanning, the defect shape and area showed good agreement with the actual defect. The proposed approach can be used as a non-contact-based online inspection and monitoring technique.

Thickness Measurements of Sub-Millimetre Thickness Foils Using Lamb Wave Dispersion

---**Kevin L. McAughey**, Rachel S. Edwards, and Steve Dixon, Department of Physics, University of Warwick, Coventry, CV4 7AL, United Kingdom; Kevin L. McAughey and Mark D. G. Potter, Sonemat Ltd., The Venture Centre, Coventry, CV4 7EZ, United Kingdom

---Industrial thickness measurements are commonplace, and can be performed during a manufacturing process as a form of quality assurance, or on working components in order to assess their integrity. Ultrasonic thickness measurements of sub-millimetre thickness samples, often referred to as foils or sheets, are typically performed using either resonance techniques, or by using delay lines with pulse-echo transducers. The use of a contact transducer with a delay line will change the boundary conditions of the foil, which will negatively impact the reliability of the results, thus a non-contact measurement technique should be used. The use of an electromagnetic acoustic transducer (EMAT) operating at resonance to determine the thickness of the sample offers a non-contact measurement, but requires prior knowledge of the material properties, including the ultrasonic velocity, and any uncertainty in these values due to changes in stress or temperature will lead to an error in the measured thickness. In order to avoid the negative effects of uncertainty in the material properties a technique relying solely on the dispersion of Lamb waves is used. This uses an approximation which relates the velocity of long-wavelength Lamb waves of the fundamental modes, A0 and S0, to the thickness of the sample. The validity of this approximation is examined, comparing the validity when using phase or group velocity, and thickness measurements on a number of samples are presented. Additionally, empirical improvements are considered to extend the range of frequency-thickness over which the approximation is valid, while maintaining the requirement for minimal knowledge of the material properties of the sample.

A Probabilistic Approach to Automatic Registration of NDE Image Data to a 3D Specimen Model

---**Elizabeth D. Gregory** and Stephen D. Holland, Iowa State University, Department of Aerospace Engineering, Center for NDE, Ames, IA 50011

---Improvements in automated acquisition and information storage have set the stage for a revolution in NDE data processing. The industry will soon be ready to combine large quantities of disconnected data into a cohesive model for each individual part and each structure. The work presented here is a step towards that larger achievement. Our goal is to prototype systems that can automatically place NDE image data into a spatial context, and to project the NDE data onto a three-dimensional specimen model such as a CAD model. We experiment with the use of cameras to identify object orientation and position. One way to do this is to identify corners and edges from the CAD model as well as high-contrast points in the images. Our system identifies all possible mappings from the corners and edges of the CAD model to the high-contrast points on the images. These candidate mappings are weighted based on their probability according to the uncertainty models for both CAD model and image.

Vibrational Modes of Thin Plates and Their Application to Flexural Ultrasound Transducers

---**Tobias Eriksson**, Steve Dixon, and S. N. Ramadas, University of Warwick, Department of Physics, Coventry, CV4 7AL, United Kingdom

---The theory of thin, vibrating plates and their modes is well understood, and some experimental verification has been achieved. Flexural ultrasound transducers use these modes to efficiently generate large amplitude waves in fluid media, where conventional piezoelectric systems suffer a performance loss due to a large impedance mismatch. But there has been little research into how the different flexural modes can be utilized, and how they affect the performance and behavior of the transducers. A flexural transducer can be excited in different ways, e.g., piezoelectrically, electromagnetically or by a high power laser. The modal frequencies, and hence also the operational frequency, of the transducer are generally only slightly affected by the generation method, and are predominantly determined by the geometry of the radius and thickness of the vibrating front face. Hence, a transducer can be designed to operate at a specific vibration mode at a particular frequency and by understanding the nature of the resonant modes, one can optimize the application dependent transducer performance. Simplified analytical models for the theory of vibrating plates was used to predict the resonant modal shapes and frequencies in the vibrating, circular transducers. Finite element modeling (FEM) was used to further investigate these modes in a more realistic system. Simple metal cap flexural transducers with different dimensions were constructed, and their behavior was investigated using laser interferometry, electrical impedance analysis and the radiated acoustic beam profile measurements. The theoretically predicted vibration modes are clearly identifiable in the experimental measurements of the flexural transducers. The front face of the flexural transducer behaves similar to a simply supported, or clamped circular plate, with similar modal frequencies. The different modes give rise to a wide variety of beam profiles, which significantly affects the directivity and hence the potential application of the transducer. Notably, two axisymmetric modes of one particular transducer, found by FEM at 180 kHz and 220 kHz respectively, had very different directivity, with a significant amount of power propagating at +15 degrees and -15 degrees for the first resonant mode and at 0 degrees for the second resonant mode.

Detectability Limitations With 3-D Point Reconstruction Algorithms Using Digital Radiography

---**Erik Lindgren**, Department of Materials and Manufacturing Technology, Chalmers University of Technology, 412 96 Göteborg, Sweden

---The 3-D positioning and sizing of defects using digital radiography can be categorized into two fundamentally different approaches. Either the linear X-ray attenuation (approximately the density) of the whole volume to be inspected is reconstructed using computerized tomography, or alternatively the 3-D positions of specific points on the surface of the defect or within the volume of the defect is derived using a small set of radiographic projections from different views, point reconstruction. The point reconstruction approach will in general require a lower inspection time, fewer X-ray projection views, and in some cases work better with planar geometries, compared to the computerized tomography approaches including the limited view tomography methods. However, the possibly decreased inspection time has the downside of increasing the uncertainty in the detectability. The detectability and the uncertainty in the 3-D positions will become highly dependent on each specific set of defect sizes and 3-D positions. If this uncertainty could be quantified then algorithms could be adjusted to automatically adapt (for example to add X-ray projection views) depending on the actual 3-D defect positions initially derived for each inspected volume. In this work these limitations and uncertainties are explored in connection to a recently published algorithm for detection, 3-D positioning, and sizing of small pore defects using digital radiography and tracking.---This work was done with the financial support from the Swedish National Aeronautical Research Program (NFFP).

Pseudo-Coloring for Ultrasonic NDE

---**Anton Van Pamel** and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Colin Brett, E.ON Technologies (Ratcliffe) Limited Technology Centre, Ratcliffe-on-Soar, Nottinghamshire, United Kingdom

---Ultrasonic imaging for NDE is limited by the challenge of detection, which relies on discriminating between objects based on their intensity. Whilst this works well in ultrasonically transparent media, in polycrystalline materials however, a host where scatterers are abundant, this is no longer the case. In such media, intensity information, as a means of interpreting an image, is compromised by the background of grain scattering noise. In a bid to improve this, it is suggested here to use pseudo-coloring to consider frequency information and distinguish objects based on the spectra of their scattered signals. This approach exploits the frequency diversity; namely the difference in frequency dependence of the noise stemming from the material's microstructure, or backscatter, and that exhibited by the targets of interest: defects. Whereas established frequency diversity techniques exploit this additional information to reconvert it into amplitude data, color allows us to encode frequency and intensity information independently. This poster showcases how this can improve interpretation of both ultrasonic B-scans and array images.

Guided Waves

Assessment of Ultrasonic NDT Methods for Highspeed Rail Inspection

---Jianzheng Cheng[1,2] and **Leonard J. Bond**[1]; [1]Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011; [2]College of Electronic and Electricity Engineering, Wuhan Textile University, Wuhan 430200, China

---Rapid and effective detection of defects rail is an increasingly important issue, particularly with increasing deployment of high speed trains and freight transportation. Historically a lot of work has been performed to investigate and improve the traditional ultrasonic rail inspections, for example by using neural networks to improve identification of defects, and using ultrasonic phased arrays to improve the image of flaws. However, the improvements made to conventional ultrasonic methods can not overcome their inherent shortcomings, which include limits to inspection speeds, shallow crack shadowing, and false calls. In order to overcome these limitations various new methods have been investigated, including using ultrasonic guided wave. This approach has shown some promise. Guided waves propagate along rather than across the rail, and are thus ideal for detecting critical transverse defects. In addition, these waves are not sensitive to surface shelling because they can run underneath these discontinuities. Finally, guided waves propagate at the speed of sound in steel and thus offer the potential of extremely high inspection speeds. The major challenge then becomes appropriate transmission and reception of the ultrasonic waves that provide both adequate sensitivity and transduction speed. This paper mainly reviews the state of the art for guided wave technologies used for rail detection. It looks at options and capabilities for transduction including EMAT's, air coupled, pulsed laser method, and wheel probe guided wave methods. It compares performances in terms of frequency ranges, energy delivered, ultrasonic wave modes excited, sensitivity, potential speeds of inspections, inspection regions, positioning and transducer angle. The advantages and disadvantages of each transduction modality for possible use in high speed railway will be reviewed. It is concluded that an EMAT and laser method, or their combination has the potential to provide a new tool for higher speed rail in-service inspection.---
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Guided Waves

PZT Guided Waves Sensor Permanently Attached on Multi-wire AGW12 Cables used as Communication Medium

---Gianpiero Trane[1] and **Rito Mijarez**[1], [1]Instituto de Investigaciones Eléctricas, Gerencia de Control, Electrónica y Comunicaciones, Calle Reforma 113, Col. Palmira, C.P. 62490, Cuernavaca, Morelos, Mexico; Arturo Baltazar[2], [2]Centro de Investigación y Estudios Avanzados del IPN, Unidad Saltillo Carretera Saltillo-Monterrey Km 13.5, C.P. 25900 Ramos Arizpe, Coahuila, México

---Guided waves communication is an alternative communication modality in which an elastic medium works as the communication channel and guided waves act as the information carrying signals. This study presents preliminary results of the design and performance of a smart active piezoelectric sensor for transmitting and receiving guided waves encoded information on multiconductors American Wire Gauge (AWG) 12 cables commonly used in domestic and industrial electric installations. The smart transmitter is composed of a microcontroller, a signal booster, a PZT crystal adhered to a copper circular plate and a 9V battery. The receiver instrumentation package comprises a PZT crystal attached to a copper circular plate and a real time digital signal processing module. Copper plates were soldered to an AWG12 multiconductor cable 4 m in length. Frequency selection was based on dispersion curves and finite element modeling and experiments of PZT crystals. The transmitter is configured to generate 60 kHz pulses to excite Longitudinal L(0,1) and Flexural F(1,1) modes. Experimental results showed that although attenuation and dispersion that characterize the media was significant, it was possible to successfully identify guided wave encoded information.

Guided Waves

Field Trials Results of Guided Wave Tomography

---**Arno Volker** and Tim van Zon, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek or TNO (Netherlands Organisation for Applied Scientific Research), Stieltjesweg 1, 2600 AD Delft, The Netherlands; Edwin van der Leden, CIT Industrial services b.v.

---Corrosion is one of the industries major issues regarding the integrity of assets. Guided wave travel time tomography is a method capable of providing an absolute wall thickness map. This method is currently making the transition from the laboratory to the field. For this purpose a dedicated data acquisition system and special purpose EMAT sensor rings have been developed. The system can be deployed for permanent monitoring and inspections. Field trials have been conducted on various pipes with different diameters, containing either liquid or gas. The main focus has been on pipe supports. The results demonstrate the successful operation of the technology in the field. Expected corrosion damage was clearly visible on the produced results enabling asset owner to make calculated decisions on the pipelines safety, maintenance and operations.

Guided Waves

Multimode Dispersion Compensated Pulse-Echo Guided Wave Inspection

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---Obtaining temporal/spatial resolution in guided wave measurements comparable to that of bulk wave measurements is impeded by the complicating effects of multimode dispersion. Transport of signals by multiple dispersive modes of propagation can transform an initially compact transient into an extended, visually unintelligible wavetrain. Guided mode inspections therefore tend to restrict measurements to regimes for which a single mode can be generated with minimal dispersion, consequently restricting the achievable temporal/spatial resolution of the measurement. The objective of the work reported here is to remove such restrictions, through implementation of wavefield measurements which accommodate the total complexity of multimode dispersed signals. Temporal and spatial Fourier analysis of guided wave fields enables a full identification of individual mode contributions, as well as associated mode dispersion characteristics, as has been demonstrated by numerous researchers. Practical implementation of spatial Fourier analysis can be achieved using appropriately designed array transducers. It is therefore conceivable that, for a given measurement configuration, processing could be implemented to effectively remove the effects of multimode dispersion, enabling operation in frequency regimes currently associated with bulk wave measurements. This paper will report on work which is exploring this possibility. Results will be presented demonstrating array-based MHz regime plate wave measurements, generating 10 or more modes, in which individual modes are isolated, effects of dispersion are removed, and temporal resolution of the original transmitted pulse is restored. Application to improved defect resolution in canonical guided wave measurements will be discussed.---This material is based on work supported by the Iowa State University Center for Nondestructive Evaluation NSF Industry-University Cooperative Research Center.

Surface Waves

Study on Thickness Measurement of Nickel Thin film using Dispersion Characteristic of Surface Wave Velocity

---Taesung Park, Byngseok Cho, and Ikkeun Park, Seoul National University of Science and Technology, Mechanical &Automotive Engineering, Seoul, Korea; Miso Kim and Seungseok Lee, Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea

---In this study, we suggest a method to measure the thickness of thin films nondestructively using dispersion characteristics of a surface acoustic wave. Nickel films with different thickness were deposited on Si(100) substrate in order to verify a change of the surface acoustic wave velocity depending on the film thickness. Matrix techniques are presented for modeling ultrasonic waves in multilayered thin films and then applied to the calculation of dispersion curves for nickel thin film. Subsequently, the surface acoustic wave velocity of the thin films with different thicknesses was measured using the V(z) curve method of scanning acoustic microscopy. The theoretical surface acoustic wave velocity from the dispersion curve and measured surface acoustic wave velocity was compared. Experimental results appeared to have trends consistent with the theoretical results from dispersion curve.

Surface Waves

Quantitative Diagnostics Of Multilayered Composite Structures With Ultrasonic Guided Waves

---**G. Bunget**[1], F.J. Friedersdorf[1], and J. K. Na[2], [1]Luna Innovations Inc., Roanoke, VA 24016; [2]Edison Welding Institute, Columbus, OH 43221

---The main objective of the current work is to develop a practical nondestructive inspection methodology for a highly sound absorbing composite structural system consisting of polymeric and metallic materials. Due to constraints in geometrical shapes and thicknesses of the composite system used in this work, ultrasonic guided wave approach has been chosen not only to characterize the acousto-elastic properties of aging polymer coating layers but also to detect internal delamination, kissing bonds, and internal cracks. Since the polymer coatings have high damping properties, less energy was dissipated into the adjacent media in the presence of delamination. Experimental measurements performed on a targeted composite system, whether it has an aluminum, carbon-fiber-composite, or steel outer casing, show promising results. Ultrasonic attenuation data seems to give a measurable correlation with the degree of aging for the inner polymer coating layer as well as with the artificially induced aforementioned inter-laminar defects. In this paper, a potential applicability of the currently developed NDI methodology to other types of multilayered composite systems is also discussed.

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Fundamentals

Photoelastic Visualization of SV Wave Propagation and Scattering

---**Zhiwu An**, Shijie Jin, Guoxuan Lian, Xiaomin Wang, Institute of Acoustics, Chinese Academy of Sciences, No. 21, Bei-Si-Huan-Xi Road, Haidian District, Beijing 100190, China (PRC)

---The scattering of elastic waves by cracks has been extensively studied theoretically, numerically, as well as experimentally since the 1950s. The photoelastic visualization technique is a method to display stress or stress waves, and its physical basis is temporary birefringent effect. This technique was extended to display elastic waves in transparent solids in 1977 by Hall, and developed by Ying in1980s. Recently, we developed a photoelastic visualization system based on modern techniques. The propagation and scattering of SV wave were studied by photoelastic technique. Firstly, we measured the central frequency, near field distance and far field directivity of wave field radiated by a shear transducer. Secondly, the propagation of creeping wave on curved surface was studied. Then, the scattered fields of SV wave by different types of cracks, such as surface breaking crack and cylindrical hole, were analyzed. Quantitative evaluation method of cracks based on photoelastic image analysis is proposed.

Fundamentals

Research on Ultrasonic Guided Waves Propagating in Pipes Embedded in Infinite Media Based on SAFE-IFE Method

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---Millions of miles of pipes are being used in both civil and mechanical engineering fields, pipes buried in infinite media, which is common, are difficult to reach, and guided waves have shown a good prospect in non-destructive testing and health monitoring for such cases. Knowledge of dispersive characteristics of guided waves propagating in pipes embedded in infinite media is of great significance for the purpose of non-destructive testing. A hybrid semi-analytical finite element method, the so-called 1D-SAFE-IFE method, is presented to compute the dispersion curves, including phase velocity dispersion curves, energy velocity dispersion curves and attenuation dispersion curves, and wave structures of both axisymmetric and non-axisymmetric wave modes. The infinite media contains a layer of finite element and a layer of infinite element, a mapped or decay function infinite element is used to avoid the reflection from the outer interface of the infinite media. Convergence problems are investigated and several general rules satisfying the convergence condition are proposed. The 1D-SAFE-IFE method can be used in both single-layered and multi-layered pipes cases, an improved 2D-SAFE-IFE method or 2D-SAFE-PML method will be able to perform the dispersive analysis of embedded waveguides of arbitrary cross-section.

Fundamentals

Fatigue Crack Detection Using Subharmonic Component with Nonlinear Boundary Conditions

---Weiliang Wu, Wenzhong Qu, and Li Xiao, Wuhan University, Department of Engineering Mechanics, Wuhan, Hubei, China; **Yanfeng Shen** and Victor Giurgiutiu, University of South Carolina, Department of Mechanical Engineering, Columbia, SC 29201

---In recent years, researchers have focused on Structural Health Monitoring (SHM) and damage detection techniques using nonlinear vibration and nonlinear ultrasonic methods. Fatigue cracks may exhibit contact acoustic nonlinearity (CAN) with distinctive features such as superharmonics and subharmonics in the power spectrum of the sensing signals. However, challenges have been noticed in the practical application of the harmonic methods. For instance, superharmonics can also be generated by the piezoelectric transducers and the electronic equipment; super/subharmonics may also stem from the nonlinear boundary conditions such as structural fixtures. It is hard to tell whether the harmonics come from the structural damage or the intrinsic nonlinear boundary conditions. The objective of this paper is to demonstrate the application of nonlinear ultrasonic subharmonic method for detecting fatigue cracks with nonlinear boundary conditions. The fatigue crack was qualitatively modeled as a single-degree-of-freedom (SDOF) system with non-classical hysteretic nonlinear interface forces at both sides of the crack surfaces. The threshold of subharmonic generation was studied, and the influence of crack interface parameters on the subharmonic resonance condition was investigated. The different threshold behaviors between the nonlinear boundary condition and the closed crack was found, which can be used to distinguish the source of nonlinear subharmonic features. To evaluate the proposed method, experiments of an aluminum beam with a fatigue crack were conducted to quantitatively verify the subharmonic resonance range. Two surface-bonded piezoelectric transducers were used to generate and receive ultrasonic wave signals. The fatigue damage was characterized in terms of a subharmonic damage index. The experimental results demonstrated that the subharmonic component of the sensing signal can be used to detect the fatigue crack and further distinguish it from inherent nonlinear boundary conditions.

Fundamentals

Simulation of the Second Harmonic Generation in Reflected Modes

---**Anne Romer**, Jin-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30318

---Implementation of the ultrasonic second harmonic generation has typically been restricted to setups such as through-transmission or Rayleigh surface waves. Recent research has evaluated the second harmonic waves generation in P- and SV- waves reflected from a stress-free surface to enable the single-sided interrogation of a specimen. This research considers the second harmonic generation in an aluminum specimen using an approach based on a perturbation method. Here the model is chosen to mimic an experimental setup where the longitudinal wave is generated at oblique angle and the reflected wave is detected using a set of wedge transducers. Due to refraction at the interface of the wedge and the specimen, it is necessary to evaluate longitudinal and shear waves, determining all second harmonic waves generated at the stress-free boundary and in the bulk. The theoretically developed model is then implemented in a commercial finite element code, COMSOL, using different angle s of incidence for increasing values of third order elastic constants. The results of this computational model verify the analytical approach. Furthermore, the computational model is used to draw important conclusions relevant to an experimental setup, including the need to avoid evolving surface waves. Finally the feasibility of the single-sided determination of the acoustic nonlinearity using reflected bulk waves is discussed.

Fundamentals

Curved Surface Energy Coefficients Integration Echo Energy Estimation Method for Pipe Inner Surface Longitudinal Crack Detection When Using Mode-Transformed Compression Wave Adaptation of Shear Wave Testing

---**Shiyuan Zhou**, Haoyu Sun, Chunguang Xu, Xiandong Cao, and Dingguo Xiao, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, China

---The echo signal energy is directly affected by the incident sound beam eccentricity or angle, for seamless pipes inner longitudinal cracks detection, when using mode-transformed compression wave adaptation of shear wave testing. A method for analysis the relationship of the echo energy to incident eccentricity is brought forward, which estimate echo energy through making two-dimension energy coefficient integration in both circumferential and axial direction. The calculation model is founded for cylinder sound beam case. In the calculation model the refraction coefficient and reflection coefficients of different sound lines in the beam are considered be different. The echo signal energy has been calculated for a particular cylinder sound beam detecting different pipes, the sound beam diameter is 0.5 inch, the pipe outside diameter and internal diameter are 79.4mm and 31.8mm, 279.4mm and 76.2mm. And two different estimate method, two-dimension integration and one-dimension (circumferential direction) integration, are carried out for comparison. It shows that the echo signal energy calculated by two-dimension integration method agrees well with experiment result, while the calculate value from one-dimension integration method have great error. This research validate the availability and reliability of this estimation method and indicate the mistakes it may cause while choice the proper eccentricity regarding the sound beam as a line or only considering the sound diameter for a curved surface.

Fundamentals

Subharmonic Resonance Caused by Contact Acoustic Nonlinearity

---**Yuji Kato**, Hirotaka Tanaka, Tatsuhiro Okamoto, and Toshihiko Sugiura, Keio University, Dept. of Mechanical Engineering, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama-shi, Kanagawa 223-8522

---It is difficult to detect a closed crack by conventional methods using reflected ultrasonic waves. Nonlinear ultrasonics is expected as a useful method for detection of closed cracks in structures. The mechanism of nonlinear responses by a closed crack is often explained with the idea of the contact acoustic nonlinearity (CAN) that is caused by collision of contact surfaces. However, the mechanism of subharmonics generated by a closed crack is not clear yet. In our previous studies, subharmonics were assumed to be generated by a nolinear spring modeling of contact surfaces. In this research, we investigate subharmonic generation, using a simplified modeling of collision between a mass and a beam. Our numerical results show that 1/2-, 1/3- and 1/4-subharmonics are generated when the excitation frequencies are about 4, 6 and 8 times the natural frequency, respectively. These characteristics are different from those of subharmonics generated by the nonlinear spring modeling. Experimental results agree well with numerical results. Therefore, subharmonics from a closed crack can be generated by such impact phenomena.

Fundamentals

Simulation of Time Reversal Beam Fields with Contacting Nonlinear Interfaces and Imaging of Crack-Like Microdamage

---**Hyunjo Jeong**, Sunjong Cho, and Kiwoong Nam, Wonkwang University, Mechanical and Automotive Engineering, Iksan, Jonbuk, Korea

---In recent ultrasonic nondestructive evaluation, nonlinear elastic wave spectroscopy (NEWS) methods were shown to be powerful tools to explore microdamage such as partially closed cracks. When combined with time reversal (TR) process, by sending back only the nonlinear components of the received signal that are time reversed, NEWS-TR can be used to either increase the energy on the retrofocusing position or to retrofocus elastic waves on the nonlinear defect. In this work, we present a simulation approach to detect and image contact acoustic nonlinearity in attenuating metallic samples by combining NEWS methods and TR process. Nonlinear interaction between elastic wave and contact interface is introduced based on a nonlinear interface stiffness model where the stiffness property of the contact interface is described as a function the nominal contact pressure. Retrofocusing quality is examined first by applying harmonic filtering with use of different signal record length in a pulse-echo testing mode. An actual crack is then simulated by gradually changing the interface stiffnesses. A beamforming algorithm is used to construct the crack localization image (location and imaging) by relating the contrast at a particular pixel to the amplitude of the reflected signal acquired by the receiver.

Fundamentals

Sensitivity Comparison of Relative Acoustic Nonlinear Parameter Measurement by Thermal Aging

---**Hogeon Seo**, Gang Ren, and Jongbeom Kim, Hanyang University, Department of Mechanical Convergence Engineering, Seoul, Korea; Kyung-Young Jhang, Hanyang University, School of Mechanical Engineering, Seoul, Korea

---The acoustic nonlinearity measurement of ultrasonic waves are being extensively researched as a promising nondestructive evaluation element. In the condition of constant propagation distance and wave number, many researchers have measured the relative second-order acoustic nonlinear parameter (β') that can be simply defined as the ratio of the amplitude of the second harmonic frequency component to the amplitude squared of the fundamental frequency component and compared them in order to identify the acoustic nonlinearity variation according to material degradation. In this study, we extended this concept to the relative third-order acoustic nonlinear parameter (γ') by defining it as the ratio of the amplitude of the third harmonic frequency component to the amplitude cubed of the fundamental frequency component. To investigate its effectiveness as a nondestructive evaluation element for the material property degradation, both the relative second-order acoustic nonlinear parameter and the relative third-order acoustic nonlinear parameter were measured for the aluminum specimens processed by heat treatment for the different times and then contrasted each other. From the experimental results, the relative third-order acoustic nonlinear parameter was more sensitive than the relative second-order acoustic nonlinear parameter that has been widely used although the amplitude of the third harmonic frequency component was lower than the amplitude of the second harmonic frequency component.---This research was supported by Nuclear Power Research and Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NRF-2013M2A2A9043241).

NDE Sensors and Systems

Development of Training Modules for Magnetic Particle Inspection

---Daigo Kosaka[1], **David J. Eisenmann**[1], Darrel Enyart[1], Norio Nakagawa[1], and Chester Lo[2], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]501 Murphy Ranch Road, Apt. 314, Milpitas, CA 95035

--- Magnetic particle inspection (MPI) is a nondestructive evaluation technique used with ferromagnetic materials. Although the application of this method may appear straightforward, MPI combines the complicated nature of electromagnetics, metallurgical material effects, fluid-particle motion dynamics, and physiological human factors into a single inspection. To fully appreciate Industry specifications such as ASTM E-1444 as a guide, users should develop a basic understanding of the many factors that are involved in MPI. The need for this basic understanding requires a streamlined description of these factors. We have developed a series of MPI training modules that try to address this requirement. The modules not only offer qualitative explanations, but try to show quantitative explanations in terms of measurement and numerical simulation data. There are five modules in all. Module #1 shows characteristics of waveforms and magnetizing methods for the MPI users to make optimum choice of a waveform and magnetizing method best suited for the inspection requirement. Module #2 explains how material properties relate to the magnetic characteristics. Module #3 shows the strength of the excitation field or the flux leakage from a crack and how it compares to the detectability of a crack by MPI. Module #4 shows how specimen statuses may influence defect detection. Module #5 shows effects of particle properties on defect detection. It is hoped that these modules will help in understanding the MPI.---This material is based upon work supported by the Federal Aviation Administration under Grant Number 10-G-002 and performed at Iowa State University's Center for NDE.

NDE Sensors and Systems

Measurement of Ultrasonic Nonlinear Parameter Using Acoustic Buffer and Laser Doppler Vibrometer

---**Dae-Cheol Seo**, Seung Hyun Cho, Chun-Su Park, and Seung-Suk Lee, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea

---Ultrasonic nonlinear parameter was measured with the aid of acoustic buffer. The acoustic buffer was introduced to make the incident wave as plain wave by applying far-field effect to ultrasonic wave from transducer. Also the acoustic buffer was used to measure the harmonic component of incident wave which make it possible to calculate the nonlinear parameter more accurately. The acoustic buffer was made of Plexiglas and designed to transmit laser light for measurement of incident wave to specimen. Ultrasonic nonlinear parameter was measured using laser Doppler vibrometer (LDV) and the effect of measuring point scatter was investigated for repeatability improvement. Fatigue damage of aluminum specimen was evaluated using ultrasonic nonlinear parameter measurement using acoustic buffer and LDV.

NDE Sensors and Systems

Measurement and Fitting Techniques for the Assessment of Material Nonlinearity with Air-Coupled Piezoelectric Receivers Using Nonlinear Rayleigh Waves

---**David E. Torello** and Laurence J. Jacobs, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332; Jin-Yeon Kim and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 30332; Jianmin Qu, Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208

---This research considers the effects of diffraction, attenuation, and the nonlinearity of generating sources on measurements of nonlinear ultrasonic Rayleigh wave propagation. A new theoretical framework for correcting measurements made with air-coupled and contact piezoelectric receivers for the aforementioned effects is provided based on analytical models and experimental considerations. A method for extracting the nonlinearity parameter β11 is proposed based on a nonlinear least squares curve-fitting algorithm that is tailored for Rayleigh wave measurements. Quantitative experiments are conducted to confirm the predictions for the nonlinearity of the piezoelectric source and to demonstrate the effectiveness of the curve-fitting procedure, and these results are compared to baseline results found in literature and other methodologies on aluminum specimens. Characterization of air-coupled piezoelectric receivers is also considered and the results are used to demonstrate the ability to use non-contact piezoelectric elements in nonlinear ultrasonic measurement setups with accuracy and efficacy.

Session 12

SESSION 12
PHASED ARRAYS II
Paul Wilcox, Chairperson
Peregrines

3:30 PM **An Investigation of Ultrasonic Array Performance for Inspecting Polycrystalline Materials**
---**Anton Van Pamel**, Peter Huthwaite, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Colin Brett, E.ON Technologies (Ratcliffe) Limited Technology Centre, Ratcliffe-on-Soar, Nottinghamshire, United Kingdom

3:50 PM **Phase Aberration Compensation of Ultrasound Pulses Propagated Through an Inhomogeneous Medium for Ultrasound Imaging Applications**
---**Mehdi Hajian**, Jeffrey Sadler, and Roman GR. Maev, Institute for Diagnostic Imaging Research, University of Windsor, Windsor, Ontario, Canada; Robert Gaspar, Department of Mechanical, Automotive and Materials Engineering, University of Windsor, Windsor, Ontario, Canada

4:10 PM **Development of a Pseudo Phased Array Technique Using EMATs for DM Weld Testing**
---**Adam C. Cobb** and Jay L. Fisher, Southwest Research Institute, Sensor Systems and NDE Technology Department, San Antonio, TX 78238; Nobuyuki Shiokawa, Toshiaki Hamano, and Ryoichi Horikoshi, IHI Corporation, Quality Control Group, Yokohama, Japan

4:30 PM **Evaluation of Friction Stir Welds with Phased Array Ultrasonic and Array Eddy Current Techniques**
---**Evgueni Todorov**, Roger Spencer, Harvey Castner, and Tim Stotler, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221-3585

4:50 PM **Post Evaluation of Rotor Weld Repairs Using Phased-Array Ultrasonic Inspections Using Intelligent Date Fusions**
---**Xuefei Guan** and Kevin S. Zhou, Siemens Corporation, Corporate Technology, Princeton, NJ 08540; El Mahjoub Rasselkorde and Waheed A. Abbasi, Siemens Energy Inc., Pittsburgh, PA 15201

3:30 PM

An Investigation of Ultrasonic Array Performance for Inspecting Polycrystalline Materials

---**Anton Van Pamel**, Peter Huthwaite, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Colin Brett, E.ON Technologies (Ratcliffe) Limited Technology Centre, Ratcliffe-on-Soar, Nottinghamshire, United Kingdom

---Microstructural noise has long hindered ultrasonic NDE of polycrystalline materials. In recent years however, arrays have enabled exciting possibilities to advance ultrasonic inspection of these materials. A Finite Element (FE) model is used to explore the different phenomena caused by grain scattering which may hinder detection of defects by an array. These include multiple scattering and beam deviation due to anisotropy; two aspects of the physics which are often required to be ignored in analytical models due to theoretical assumptions or computational limitations. We rely on a GPU based FE solver, Pogo, to provide fast computation and thereby enable parametric studies. The impact on array detection performance of varying array centre-frequency and aperture size is investigated.

3:50 PM

Phase Aberration Compensation of Ultrasound Pulses Propagated Through an Inhomogeneous Medium for Ultrasound Imaging Applications

---**Mehdi Hajian**, Jeffrey Sadler, and Roman GR. Maev, Institute for Diagnostic Imaging Research, University of Windsor, Windsor, Ontario, Canada; Robert Gaspar, Department of Mechanical, Automotive and Materials Engineering, University of Windsor, Windsor, Ontario, Canada

---Phase aberration induced by inhomogeneities of the propagation path of ultrasonic waves is a major issue in ultrasound imaging for industrial and medical applications. This phase aberration results in focus degradation of the ultrasound field and consequently affects the image quality by decreasing both point resolution and contrast resolution, which are indexes for distinguishability between isolated scatters and speckle patterns, respectively. In this study, a new method is proposed to estimate the phase aberration induced by the inhomogeneous path and subsequently to compensate for this aberration effect in a phased array system. In this method the echoes backscattered from the aberrator are collected and decomposed into their Gaussian parameters using a space alternative generalized expectation maximization (SAGE) algorithm. The estimated parameters of unwrapped phase are then used to calculate the delays for each element. Subsequently, the refraction effects are calculated using a nonlinear ray tracing technique. The algorithms were implemented on an ultrasound advanced open platform system (ULA_OP) connected to a 2 MHz linear transducer with 128 elements and 0.17 mm pitch. Experiments were carried out using a physical aberrator created by a custom designed phantom interposed between the array and the targets in a water tank. The phantom is composed of a porous layer with a highly attenuative structure sandwiched between two compact layers. The sound velocity of the middle layer is smaller than the compact layers and the thickness of the phantom varies across the transducer surface. From the experimental results it was observed that the phase aberration is significant when the aberrator is thick and is placed close to the transducer aperture. However, the results obtained from the phase aberration compensation procedure showed that the proposed method was able to considerably reduce the effects of the aberrator, producing images nearly identical to those generated in the absence of aberrations (control case). Furthermore, the focus qualities for various cases are evaluated using 2-D mapping of the acoustic pressure field with a hydrophone. The comparisons show that the full width at half maximum (-6 dB) along the lateral direction for the reception through the aberrator averaged 80% greater than the corresponding value for the control case, while the proposed phase aberration compensation technique reduced the average lateral width to a value that is only 20% greater than the one for the control case.---This work was possible due to the financial support of the US Office of Naval Research (ONR) and the Ontario Brain Institute and Federal Economic Development Agency for Southern Ontario.

4:10 PM

Development of a Pseudo Phased Array Technique using EMATs for DM Weld Testing

---**Adam C. Cobb** and Jay L. Fisher, Southwest Research Institute, Sensor Systems and NDE Technology Department, San Antonio, TX 78238; Nobuyuki Shiokawa, Toshiaki Hamano, and Ryoichi Horikoshi, IHI Corporation, Quality Control Group, Yokohama, Japan

---Ultrasonic inspection of dissimilar metal (DM) welds in piping with cast austenitic stainless steel (CASS) has been an area ongoing research for many years given its prevalence in the petrochemical and nuclear industries. A typical inspection strategy for pipe welds is to use an ultrasonic phased array system to scan the weld from a sensor located on the outer diameter (OD) of the pipe. These inspection systems generally refract either longitudinal or shear vertical (SV) waves at varying angles to inspect the weld radially. In DM welds, however, the welding process can produce a columnar grain structure in the CASS material in a specific orientation. This columnar grain structure can skew ultrasonic waves away from their intended path, especially for SV and longitudinal wave modes. Studies have shown that inspection using the shear horizontal (SH) wave mode significantly reduces the effect of skewing. Electromagnetic acoustic transducers (EMATs) are known to be effective for producing SH waves in field settings. This paper presents an inspection strategy that seeks to reproduce the scanning and imaging capabilities of a commercial phase array system by using EMATs. A custom-built EMAT was used to collect data at multiple propagation angles, and a processing strategy known as the synthetic aperture focusing technique (SAFT) was used to combine the data to produce an image. Results are shown using this pseudo phased array technique to inspect samples with a DM weld and artificial defects, demonstrating the potential of this approach in a laboratory setting. Recommendations for future work to transition the technique to the field are also provided.

4:30 PM

Evaluation of Friction Stir Welds with Phased Array Ultrasonic and Array Eddy Current Techniques

---**Evgueni Todorov**, Roger Spencer, Harvey Castner, and Tim Stotler, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221-3585

---Friction stir welding (FSW) is used to join aluminum extrusions to form lightweight panels used in the construction of Navy ships. The National Shipbuilding Research Program—Advanced Shipbuilding Enterprise (NSRP- ASE) sponsored a large study to investigate technologies that could be used to improve the quality assurance capabilities for inspection of these FSW panels. To address the challenging FSW quality specifications, phased array ultrasonic (PAUT) and array eddy current (AEC) nondestructive evaluation (NDE) techniques were selected and developed. Statistically significant number of FSW specimens containing kissing bonds, incomplete penetration (IP) and incomplete consolidation (IC) were fabricated and tested with high sensitivity and resolution PAUT and AEC techniques. The detection rate and probability of detection were obtained at several detection thresholds. While baseline FSW specimens (no flaw) were correctly classified with very low false call probability, the detection pattern on specimens with flaws was intermittent and required deviation from standard examination practices and procedures. Both advanced techniques demonstrated good detection capabilities. New technique for tracking the weld seam with eddy current sensor was also demonstrated. The NDE results were well correlated to other mechanical and fatigue tests conducted under the same project.

4:50 PM

Post Evaluation of Rotor Weld Repairs Using Phased-Array Ultrasonic Inspections Using Intelligent Date Fusions

---**Xuefei Guan** and Kevin S. Zhou, Siemens Corporation, Corporate Technology, Princeton, NJ 08540; El Mahjoub Rasselkorde and Waheed A. Abbasi, Siemens Energy Inc., Pittsburgh, PA

---The study presents an intelligent phased-array ultrasonic data reconstruction and fusion method for rotor weld repairs. Data from different scan types and waves are used to cover different flaws in the weld repairs. A three-dimensional data reconstruction and mapping algorithm is developed to process all data to generate a volume which can be overlaid with the structure model for visual flaw inspection and identification. A threshold-based flaw quantification rule is used to identify indications and distance-gain-size method is used to quantify the size of an identified indication. A practical example is provided to illustrate the overall method.

Session 13

SESSION 13
TERAHERTZ NDE
Yuri A. Plotnikov and Chien-Ping Thomas Chiou, Co-Chairpersons
Salmon-Snake

3:30 PM **Design and Development of an Electrically Controlled Beam Steering Mirror for Microwave Tomography**
---**Amin Tayebi**, Junyan Tang, Pavel Roy Paladhi, Lalita Udpa, and Satish Udpa, Department of Electrical and Computer Engineering, College of Engineering, Michigan State University, 428 S. Shaw Lane, East Lansing, MI 48824-1226

3:50 PM **Generation of a Class of Filtered Backpropagation Techniques for Reconstruction with Lower Angular Coverage**
---**Pavel Roy Paladhi**, Amin Tayebi, Lalita Udpa, and Satish Udpa, Department of Electrical and Computer Engineering,Michigan State University, East Lansing, MI-48824; Ashoke K. Sinha, Department of Statistics and Probability, Michigan State University, East Lansing, MI-48824

4:10 PM **Real Time THz Imaging Based on Frequency Upconversion Using a Near-Infrared CMOS Camera**
---Patrick F. Tekavec, **Ian R. Mcnee**, and Vladimir G. Kozlov, Microtech Instruments, Inc., Eugene, OR 97401

4:30 PM **Feasibility Study of THz Inspection of Electric Cables in Nuclear Power Plants**
---**Chien-Ping T. Chiou**[1] and Feng Yu[2], [1]Center for NDE, Iowa State University, Ames, Iowa 50011; [2]Electric Power Research Institute, Charlotte, NC 28262

4:50 PM **Alternating Current Potential Drop for Material Properties and Case Depth of Hardened Steel**
---**Mohammad R. Quddes**, Yuan Ji, and John R. Bowler, Iowa State University, Department of Electrical Engineering, Center for NDE, Ames, IA 50011

3:30 PM

Design and Development of an Electrically Controlled Beam Steering Mirror for Microwave Tomography

---**Amin Tayebi**, Junyan Tang, Pavel Roy Paladhi, Lalita Udpa, and Satish Udpa, Department of Electrical and Computer Engineering, College of Engineering, Michigan State University, 428 S. Shaw Lane, East Lansing, MI 48824-1226

---Applications of microwave imaging in NDE range from detection of defects in dielectric and composite materials to biomedical imaging for early detection of carcinoma. Traditional microwave tomography involves illumination of the region of interest (ROI) at different angles and collection of scattered field data 360° around the test object. However, the conventional microwave setup has a number of drawbacks for practical implementation such as high cost of multiple transceiver pairs, circuit complexity due to transceiver switching for projection data acquisition, antenna compensation algorithms, etc. This paper presents a new active microwave imaging system employing a beam steering mirror. An electronically reconfigurable reflectarray antenna, with high steering capability, is used to deflect the beam in different directions in order to generate multi-angle projection data. The system uses a single source instead of transceiver arrays which greatly reduces the overall cost. Moreover, the region of interest (ROI) need not be enclosed in a gantry for generating a 360° projection data and hence there is no constraint on object dimensions, therefore imaging of larger dielectric materials such as laminate structures and airplane wings would be possible. Design, modeling and experimental results of an electronically tunable single unit cell of the reflectarray antenna was presented previously. The work conducted on the unit cell was extended to build a 10x10 element reflectarray antenna. This paper describes the measured radiation pattern and beam steering capabilities of the antenna. Tomographically reconstructed images of dielectric samples using the new microwave tomography imaging system will be presented.

3:50 PM

Generation of a Class of Filtered Backpropagation Techniques for Reconstruction with Lower Angular Coverage

---**Pavel Roy Paladhi**, Amin Tayebi, Lalita Udpa and Satish Udpa, Department of Electrical and Computer Engineering,Michigan State University, East Lansing, MI-48824; Ashoke K. Sinha, Department of Statistics and Probability, Michigan State University, East Lansing, MI-48824

---Diffraction tomography using microwaves is an active field of research in the last few decades. Microwave tomography has application in medical imaging as well as non-destructive testing in civil, automotive and aviation industry. Ideally, in conventional tomographic imaging, projection measurements from interrogating waves are taken around the test sample over a range of 360°. However, in many practical problems the angular scan range for obtaining projection measurements of the region of interest (ROI) is physically limited. With limited angular coverage, special schemes for image reconstruction are required. The Fourier Diffraction Projection Theorem shows that there are certain redundancies in the full 360° projection dataset in a traditional tomographic setup. Previously, the use of these redundancies (through weighted filtering of Fourier space projection data) to generate an initial reconstruction was briefly explored and combined with a minimization technique (Total Variation) to generate a reconstructed image from a highly limited angular coverage projection data. In this paper a procedure to create a class of weighting filters that can be applied to the Fourier space data is outlined and tested using simulated data. The modified Fourier space data under ideal noiseless conditions are equivalent to the conventional projection dataset. However in the presence of noise or when angular coverage is less than 270°, the backpropagation algorithm applied on the weighted Fourier projection dataset generates different artifacts due to sub-minimal coverage, noise and discrete sampling. In this paper, attempts are made towards identifying an ideal weighting filter set to minimize the effects of limited angular coverage below the minimal coverage.

4:10 PM

Real Time THz Imaging Based on Frequency Upconversion Using a Near-Infrared CMOS Camera

---Patrick F. Tekavec, **Ian R. Mcnee**, and Vladimir G. Kozlov, Microtech Instruments, Inc., Eugene, OR 97401

---Numerous biological and chemical compounds have unique absorption features in the THz (0.1 – 10 THz) region, making the use of THz waves appealing for imaging in defense, security, biomedical imaging, and monitoring of industrial processes. THz frequencies, unlike other optical radiation, can pass through many substances such as paper, clothing, ceramic, etc. with little attenuation. However, performance of THz imaging systems is limited by the lack of high power sources as well as sensitive detectors and detector arrays operating at room temperature. Here we present a video-rate imaging system based on upconversion of THz into the mid-IR. The source for the system is based on intracavity difference frequency generation, and gives a high average THz power (1 mW) and high peak power pulses (>1W) ideal for nonlinear processes. The mixing of narrowband THz pulses (centered at 1.5 THz) with strong IR picosecond pulses at 1064 nm in QPM-GaAs generates sidebands separated from the IR spectrum by the THz frequency. High speed detection of the upconverted signal with a CMOS camera is enabled by the removal of the strong IR background.

4:30 PM

Feasibility Study of THz Inspection of Electric Cables in Nuclear Power Plants
---**Chien-Ping T. Chiou**[1] and Feng Yu[2], [1]Center for Nondestructive Evaluation, Iowa State University, Ames, Iowa 50011; [2]Electric Power Research Institute, Charlotte, NC 28262

---Electric cables are essential components in nuclear power plants (NPP). The cable condition is essential to ensure the performance of the connected equipment's nuclear safety-related function and the reliable and affordable operation of the equipment in the design basis operation environment for the required period. Without knowing the cable condition and remaining life of the cable system, a conservative life management approach will require costly replacement and repair. Terahertz radiation (THz), as an emerging NDE modality in recent years, is particularly powerful for characterizing and inspecting dielectric materials including plastics and rubbers. To assess the feasibility of THz imaging in meeting such inspection needs for NPP electric cables, a feasibility study was carried out on actual NPP cable samples. In this paper, we present the preliminary results of inspecting these samples using a time-domain pulsed system in reflection mode. The focus was aimed at assessing the effectiveness of THz imaging capability in terms of penetration, sensitivity to dielectric material property variation, non-contact nature and resolution. We also discuss the necessary hardware renovations in order to overcome difficulties in inspection setup.---This work was completed in collaboration with the Electric Power Research Institute and performed in the Center for Nondestructive Evaluation at Iowa State University.

4:50 PM

Alternating Current Potential Drop for Material Properties and Case Depth of Hardened Steel

---**Mohammad R. Quddes**, Yuan Ji, and John R. Bowler, Iowa State University, Department of Electrical Engineering, Center for NDE, Ames, IA 50011

---Multi-frequency alternate current potential drop measurements have been made on case hardened specimens to evaluate the case depth of case hardened steels using a four point probes. The separation between contact points is 3 mm for one of the probes used for these measurements. To reduce the mutual inductance between the driver and pick-up pins, a printed circuit board has been used to keep the electrical connects to the pins close to the surface of the material. The case depth is found from the low frequency measurement. The measurement have been conducted for frequencies from 1 Hz to 10 kHz. The real part of the voltage phasor representing the AC potential drop is used to evaluate the depth. The imaginary part includes a contribution due to mutual induction between driver and pick-up circuits. A correction has been made to eliminate effect of mutual induction in the imaginary part. To estimate the case depth of the hardened samples, the measured potential drop has been fitted to theoretical estimates. The substrate material properties of the hardened samples are extracted from multi-frequency potential drop measurement on non-harden samples. A theoretical inverse estimation of the material properties has been obtained from the potential drops. The estimated case hardened depths are found approximately 1.2 mm, 1.5 mm and 1.6 mm. The results agree with the hardness profiles revealed from destructively measurement.

---This work was supported by an SBIR project with AlphaSense, Inc., 510 Philadelphia Pike, Wilmington, DE 19809 and performed at the Center for NDE at Iowa State University.

Session 14

Tuesday, July 22, 2014

SESSION 14

NUCLEAR REACTORS I

S. W. Glass and Darryl Butt, Co-Chairpersons
Cottonwoods-Firs

3:30 PM **A Study on the Pseudo Interface Wave Technique for CRDM Weld Defects in Nuclear Power Plants**
---**Jaesun Lee**, Junpil Park, and Younho Cho, School of Mechanical Engineering, Pusan National University, Pusan, South Korea; Keun-Bae Park, Hyung Huh, and Dong-Ok Kim, Korea Atomic Energy Research Institute, Daejeon, South Korea

3:50 PM **Remote Visual Inspection of NRU Reactor Vessel Outer Annulus**
---**Paul A. Rochefort** and Eli Simova, Inspection, Monitoring and Dynamics Branch Atomic Energy of Canada Limited Chalk River Laboratories, Chalk River, ON, Canada, K0J 1J0

4:10 PM **Finite Element Modeling of Wall Loss Sizing in a Steam Generator Tube using a Pulsed Eddy Current Probe**
---**V. K. Babbar** and B. Lepine, Atomic Energy of Canada Limited, Chalk River Laboratories, Chalk River, Ontario, K0J 1J0, Canada; J. Buck, P. R. Underhill, and T. W. Krause, Royal Military College of Canada, Department of Physics, Kingston, Ontario, K7K 7B4, Canada; J. Morelli, Queen's University, Department of Physics, Engineering Physics and Astronomy, Kingston, Ontario, Canada

4:30 PM **3D Model Generation Using an Airborne Swarm**
---Ruaridh Clark, Giuliano Punzo, and Malcolm Macdonald, University of Strathclyde, Department of Mechanical and Aeronautical Engineering, Glasgow, United Kingdom; Gordon Dobie, Rahul Summan, **Charles Macleod**, and Gareth Pierce, University of Strathclyde, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom

4:50 PM **Automated Massive NDE Image Analysis, Text and Feature Abstracting, and Big Data Analysis of Structural Health Monitoring for Preventing Catastrophic Failure of Aging Structures**
---**Jeffrey T. Fong**[1], Pedro V. Marcal[2], James J. Filliben[3], and N. Alan Heckert[3], [1]Applied & Computational Math. Div., NIST, Gaithersburg, MD 20899-8910; [2]Chief Scientist, ANLIP Code Development, MPACT Corporation, Oak Park, CA 91377; [3]Statistical Engineering Division

5:10 PM **Acoustic Emission Signal Processing Technique to Characterize Reactor In-Pile Phenomena**
---**Vivek Agarwal**, Department of Human Factors, Controls, and Statistics, Idaho National Laboratory, Idaho Falls, ID 83401; Magdy S. Tawfik, Nuclear Science and Technology Directorate, Idaho National Laboratory, Idaho Falls, ID 83401; James A. Smith, Department of Fuel Performance and Design, Idaho National Laboratory, Idaho Falls, ID 83401

3:30 PM

A Study on the Pseudo Interface Wave Technique for CRDM Weld Defects in Nuclear Power Plants

---**Jaesun Lee**, Junpil Park and Younho Cho, School of Mechanical Engineering, Pusan National University, Pusan, South Korea; Keun-Bae Park, Hyung Huh, and Dong-Ok Kim, Korea Atomic Energy Research Institute, Daejeon, South Korea

---The nuclear power plant inspection is very important for the safety issue. However due to some radiation and geometric problems, the detection of CRDM(Control Rod Drive Mechanism) can be very difficult by using conventional Ultrasonic Testing method. Also the shrink fit boundary condition can also be an obstacle for the inspection In this paper, instead of conventional Ultrasonic Testing, guided wave was used for the detection of some complicated structures. The CRDM nozzle was installed in reactor head with perfect shrink fit condition by using stainless steel. The wave amplitude distribution on the circumferential direction was calculated with various boundary conditions and the experimental result shows a possibility of the defect detection on J-groove weld.

3:50 PM

Remote Visual Inspection of NRU Reactor Vessel Outer Annulus
---**Paul A. Rochefort** and Eli Simova, Inspection, Monitoring and Dynamics Branch
Atomic Energy of Canada Limited Chalk River Laboratories, Chalk River, ON, Canada, K0J 1J0

---The National Research Universal (NRU) nuclear reactor is a heavy water moderator pool reactor. The 3.5 m diameter by 3.7 m high aluminum reactor vessel is encircled by a 152 mm annular gap between the exterior of the vessel and the rest of the reactor structure. The annulus, referred to as the J-Rod annulus, is designed for neutron irradiation of material samples and other irradiation tests. Because corrosive agents are created by the interaction between ionizing radiation and gasses present in the annulus, the aluminum surfaces within the annulus are subject to ongoing corrosion. As part of the reactor's system life-management program, it was decided that a dedicated remote visual inspection system was needed to inspect and monitor the condition of the annulus' walls and components. Since access to the annulus is restricted to a limited number of 50-mm diameter ports, situated 5 m above the vessel on the reactor's top deck, a specialized tool with a radiation resistant lighting and imaging system was designed and built to perform inspections. This paper details the key design features of the 10 m long, five-axis remote visual inspection system, the components and instrumentation used, the methods used to make sub-millimeter quantitative dimensional measurements, and the factors, such as radiation-induced image speckle and tool movement, that affect the resolution and accuracy of measurements.

4:10 PM

Finite Element Modeling of Wall Loss Sizing in a Steam Generator Tube using a Pulsed Eddy Current Probe

---**V. K. Babbar** and B. Lepine, Atomic Energy of Canada Limited, Chalk River Laboratories, Chalk River, Ontario, K0J 1J0, Canada; J. Buck, P. R. Underhill, and T. W. Krause, Royal Military College of Canada, Department of Physics, Kingston, Ontario, K7K 7B4, Canada; J. Morelli, Queen's University, Department of Physics, Engineering Physics and Astronomy, Kingston, Ontario, Canada

---Pulsed eddy current (PEC) technology is being developed to address challenges in nuclear steam generator (SG) inspection and maintenance. The main focus is to target inspection issues associated with the tube-to-support plate interface, especially measurement of gap and detection of support-plate degradation and fouling. These issues can lead to tube fretting and corrosion, and eventual loss of SG efficiency. The PEC signals produced during gap measurements may, in general, include contributions from a number of other effects, such as tube eccentricity, tilt, wall loss or fretting, support plate material and geometry, and fouling. Recent work reports the application of finite element modeling to design a PEC probe with optimum sensitivity to changes in gap and offset between SG tubes and support plates [1]. The present work focuses on sizing wall loss on the outer surface of a SG tube to simulate tube fretting in the presence of a support plate and to assess the effect wall loss has on gap measurements. Models include a PEC probe comprising a central transmit coil and four receive coils placed within a SG tube, and the assembly placed within a cylindrical steel collar. The receive signals are obtained for five different wall sizes and analyzed using modified Principal Components Analysis. The experimental results obtained from a similar sample/probe configuration are in good agreement with model predictions.

Reference:

1. Krause TW, Babbar VK, and Underhill PR, "A Pulsed Eddy Current Probe for Inspection of Support Plates from within Alloy-800 Steam Generator Tubes," in Rev. Prog. Nondest. Eval. Vol. 33, edited by: DE Chimenti. Nelville, New York (2014 Am. Inst. Phys.) pp. 1352-1358.

4:30 PM

3D Model Generation Using an Airborne Swarm

---Ruaridh Clark, Giuliano Punzo, and Malcolm Macdonald, University of Strathclyde, Department of Mechanical and Aeronautical Engineering, Glasgow, United Kingdom; Gordon Dobie, Rahul Summan, **Charles Macleod**, and Gareth Pierce, University of Strathclyde, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom

---Using artificial potential functions to provide co-ordination between multiple inspection UAVs, the authors herein demonstrate full 3D modelling capability based on a hybrid visual & photogrammetric system. The operation of the system is demonstrated by generating a full 3D surface model of an intermediate level waste nuclear storage drum. Such drums require periodic inspection to ensure that drum distortion or corrosion is carefully monitored. Inspection is performed by multiple airborne platforms, which visually inspect by autonomously executing a corkscrew flight-path around a target. This system would enable rapid inspection of structures that are inaccessible to on-surface remote vehicles and are in human-hazardous environments. A full three-dimensional model of the target is then constructed in post-processing through photogrammetry analysis of the visual inspection data to generate a surface-meshed model. The aerial vehicles are commercially available Parrot AR. Drone quadcopters controlled through a computer interface connected over an IEEE 802.11n (WiFi) network, implementing a distributed controller for each vehicle. The inspection environment uses a tracking system to precisely monitor the position of each aerial vehicle within the enclosure. This enables the autonomous and distributed elements of the control scheme to be retained, while alleviating the vehicles of the control algorithm's computational load. The control scheme relies on a novel artificial potential function, which defines a drone's relationship with the target by applying a repulsive potential to avoid collisions, an attractive potential to maintain a set distance and an orientation function to drive the circular motion. This function enables complete circumferential coverage with mutual repulsive interactions between the drones preventing vehicle collisions. Coverage along the height of the object can be assured as a function of the altitude gain per rotation and number of vehicles. Using a swarm of vehicles, the time until complete coverage can be significantly reduced.

4:50 PM

Automated Massive NDE Image Analysis, Text and Feature Abstracting, and Big Data Analysis of Structural Health Monitoring for Preventing Catastrophic Failure of Aging Structures (*)

---**Jeffrey T. Fong**[1], Pedro V. Marcal[2], James J. Filliben[3], and N. Alan Heckert[3],
[1]Applied & Computational Math. Div., NIST, Gaithersburg, MD 20899-8910; [2]Chief Scientist, ANLIP Code Development, MPACT Corporation, Oak Park, CA 91377;
[3]Statistical Engineering Division, NIST, Gaithersburg, MD 20899-8980

---In this paper, we present the mathematical basis of a prototype Automated Natural Language and Image Processing tool named ANLIP and the seamless link with a statistical data analysis software named DATAPLOT to assist big data analysis of structural health monitoring in a complete package from NDE-image analysis, microstructural feature extraction, micro-crack growth rate measurement, fatigue and fracture-database-assisted life cycle modeling, to residual life cycle prediction with rigorous uncertainty bounds for real-time prevention of catastrophic failure of aging high-consequence structures and components such as helicopters, jet aircrafts, nuclear reactor pressure vessels and piping. Key to the success of the PYTHON-based ANLIP code is the development of a design-of-experiments (DEX) approach to statistical parsing of natural language-based information such as feature extracting of NDE images and text abstracting of failure event reports. The statistical parsing is done in two distinct phases: (1) A context-free parsing phase. (2) A semantics parsing phase where a uniqueness filtering technique is introduced via the Chinese language as an intermediary. The parsing is followed by a powerful information representation tool known as "Conceptual Dependency," originally due to Schank (1972). Examples of processing 10,000 NDE images to obtain defect type and size distributions, or, multiple-crack initiation and growth rate

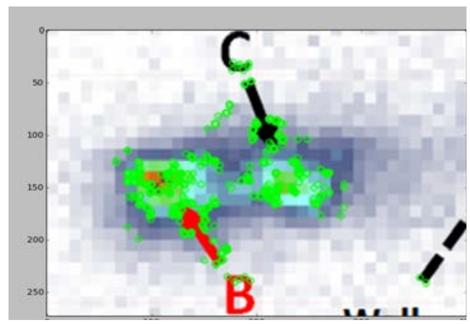

Fig. 1

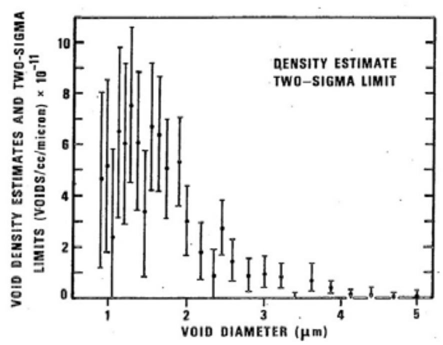

Fig. 2

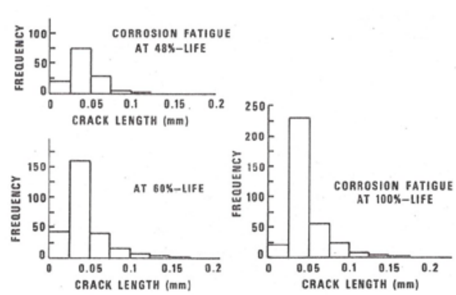

Fig. 3

(*) Contribution of the U.S. National Inst. of Standards & Technology (NIST). Not subject to copyright.

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Acoustic Emission Signal Processing Technique to Characterize Reactor In-Pile Phenomena

---**Vivek Agarwal**, Department of Human Factors, Controls, and Statistics, Idaho National Laboratory, Idaho Falls, ID; Magdy S. Tawfik, Nuclear Science and Technology Directorate, Idaho National Laboratory, Idaho Falls, ID; James A. Smith, Department of Fuel Performance and Design, Idaho National Laboratory, Idaho Falls, ID

---Existing and developing advanced sensor technologies and instrumentation will allow non-intrusive in-pile measurement of temperature, extension, and fission gases when coupled with advanced signal processing algorithms. The transmitted measured sensor signals from inside to the outside of containment structure are corrupted by noise and are attenuated, thereby reducing the signal strength and the signal-to-noise ratio. Identification and extraction of actual signal (representative of an in-pile phenomenon) is a challenging and complicated process. In the paper, empirical mode decomposition technique is utilized to reconstruct actual sensor signal by partially combining intrinsic mode functions. Reconstructed signal will correspond to phenomena and/or failure modes occurring inside the reactor. In addition, it allows accurate non-intrusive monitoring and trending of in-pile phenomena.

Session 15

SESSION 15
ADDITIVE MANUFACTURING II
Martin Spies and Joachim Bamberg, Co-Chairpersons
Pines-Willows

3:30 PM **Thermographic Process Monitoring in Powderbed Based Additive Manufacturing**
---**Harald Krauss**, iwb Anwenderzentrum Augsburg, der TU München, Beim Glaspalast 5, 86153 Augsburg, Germany

3:50 PM **Ultrasonic Online Monitoring of Additive Manufacturing Processes Based on Selective Laser Melting**
---Hans Rieder, Alexander Dillhoefer, and **Martin Spies**, Fraunhofer Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany; Joachim Bamberg and T. Hess, MTU Aero Engines GmbH, Department TAFP, Dachauerstrasse 665, 80995 Munich, Germany

4:10 PM **Nondestructive Testing Challenges of Select Laser Melt Components**
---**Steve James**, Aerojet Rocketdyne, P. O. Box 7922, Canoga Park, CA 91309

4:30 PM **Validation of In-Plane Modulus on CMC Materials Using a Dry-Couplant Ultrasonic Method**
---**R. T. Ko[1]**, J. L. Blackshire[2], and M. Y. Chen[1], [1]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120; [2]Air Force Research Laboratory, AFRL/RXLP, 2230 Tenth Street, Wright Patterson AFB, OH 45433-7817

4:50 PM **Ultrasonic Contact Surface Imaging of Bond Integrity in Foam-Based Hybrid CMC Composite Materials**
---**R. T. Ko[1]**, J. L. Blackshire[2], and M. Y. Chen[1], [1]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120; [2]Air Force Research Laboratory, AFRL/RXLP, 2230 Tenth Street, Wright Patterson AFB, OH 45433-7817

3:30 PM

Thermographic Process Monitoring in Powderbed Based Additive Manufacturing
---**Harald Krauss**, iwb Anwenderzentrum Augsburg, der TU München, Beim Glaspalast 5, 86153 Augsburg, Germany

---Selective Laser Melting is utilized to build metallic parts directly from CAD-Data by solidification of thin powder layers through application of a fast scanning laser beam. In this study layer wise monitoring of the temperature distribution is used to gather information about the process stability and the resulting part quality. The heat distribution varies with different kinds of parameters including scan vector length, laser power, layer thickness and inter-part distance in the job layout which in turn influence the resulting part quality. By integration of an off-axis mounted uncooled thermal detector the solidification as well as the layer deposition are monitored and evaluated. Errors in the generation of new powder layers normally result in a locally varying layer thickness that may cause poor part quality. For effect quantification, the locally applied layer thickness is determined by evaluating the heat-up of the newly deposited powder. During the solidification process space and time-resolved data is used to characterize the zone of elevated temperatures and to derive locally varying heat dissipation properties. Potential quality indicators are evaluated and correlated to the resulting part quality: Thermal diffusivity is derived from a simplified heat dissipation model and evaluated for every pixel and cool-down phase of a layer. This allows the quantification of expected material homogeneity properties. Maximum temperature and time above certain temperatures are measured in order to detect hot spots or delamination issues that may cause a process breakdown. Furthermore, a method for quantification of sputter activity is presented. Since sputter activity indicates instable melt dynamics this can be used to identify parameter drifts, improper atmospheric conditions or material binding errors. The resulting surface structure after solidification complicates temperature determination on the one hand but enables the detection of potential surface defects on the other hand. These issues and proper key figures for thermographic monitoring of the Selective Laser Melting process are discussed in the paper. Even though microbolometric temperature measurement is limited to repetition rates in the Hz-regime and sub megapixel resolution, current results show the feasibility of process surveillance by thermography for a limited section of the building platform in a commercial system.

3:50 PM

Ultrasonic Online Monitoring of Additive Manufacturing Processes Based on Selective Laser Melting

---Hans Rieder, Alexander Dillhoefer, and **Martin Spies**, Fraunhofer Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany; Joachim Bamberg and T. Hess, MTU Aero Engines GmbH, Department TAFP, Dachauerstrasse 665, 80995 Munich, Germany

---Additive manufacturing processes have been investigated since the late 1980s and some of them have become commercially available. With Selective Laser Melting (SLM), components can be produced by localized melting of successive layers of metal powder. In this process, a fast scanning laser beam is steered to selectively melt the powder on the basis of CAD-data. In comparison with today’s conventional techniques, this way of manufacturing allows for considerably more freedom in designing and has a tremendous economic potential. Thus, it is particularly interesting for the production of geometrically complex components. At MTU, such sophisticated components have already been manufactured for aero engines from the heat-resistant nickel alloy Inconel 718 using SLM processes. To ensure the quality, the starting powder and the manufacturing parameters are supervised. After build-up, the components are inspected and evaluated employing various nondestructive techniques. In order to be able to describe and to understand the complex dynamics of the SLM processes more accurately, online ultrasonic measurements have been performed for the first time. In this contribution, we report on the integration of the measurement technique into the manufacturing facility. We present first results and evaluations on the basis of generalized B-scans recorded during the build-up of test specimens, which is based on single layers of 40 µm thickness. The analysis of the ultrasonic signals allows to infer information about the fusion of the single layers and about the temporal formation of material defects. Based on our results, we also discuss the further potential of ultrasonic measurements, e.g. in view of the evaluation of porosity and residual stresses.

4:10 PM

Nondestructive Testing Challenges of Select Laser Melt Components
---**Steve James**, Aerojet Rocketdyne, P. O. Box 7922, Canoga Park, CA 91309

---The select laser melt process is an additive manufacturing process. Unlike the subtractive manufacturing process of machining and/or welding material to produce a desired configuration this process melts metal layer by layer to create the desired configuration. The subtractive manufacturing process provided nondestructive testing at appropriate steps in the component's fabrication allowing access for nondestructive testing. The very nature of this new additive manufacturing process eliminates many of those opportunities. This paper explores some of the challenges and results that have been learned in the early material and nondestructive testing development at Aerojet Rocketdyne using the Select Laser Melt.

4:30 PM

Validation of In-Plane Modulus on CMC Materials Using a Dry-Couplant Ultrasonic Method

---R. T. Ko[2], J. L. Blackshire[1], and M. Y. Chen[1], [1]Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; [2]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

---A mechanical test was conducted to validate the in-pane modulus estimated on CMC materials using a dry-couplant ultrasonic method. To minimize the variation of mechanical properties in specimens used in two independent studies, a pristine CMC tensile specimen was cut into two halves. On the first half of the specimen, a tensile test at low stress levels was conducted. The modulus of elasticity was derived from the slope of the stress-stain curves. On the second half of the specimen, an ultrasonic contact technique was used to assess the in-plane modulus. This technique employs a dry-couplant for materials in which liquid couplant is not desirable. An ultrasonic guided wave of the lowest symmetrical mode was generated and received in the materials in a through-transmission mode. The test results showed good agreement between the modulus values derived from these two independent tests on two types of CMC materials. Potential applications of using in-plane modulus for in-process material assessment will also be presented.

4:50 PM

Ultrasonic Contact Surface Imaging of Bond Integrity in Foam-Based Hybrid CMC Composite Materials

---**R. T. Ko**[2], J. L. Blackshire[1], and M. Y. Chen[1], [1]Air Force Research Laboratory, AFRL/RXLP, 2230 Tenth Street, Wright Patterson AFB, OH 45433-7817; [2]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120

---An ultrasonic contact surface imaging technique has been employed to study the bond integrity between a CMC facesheet and a CMC stiffener. The technique, developed earlier for inspecting a PMC/foam interface, integrates a novel pitch-catch wedge for the generation and detection of Lamb waves of the lowest order anti-symmetric mode into a traditional C-scan system. Unlike a conventional ultrasonic C-scan, the sample was not immersed in water but a thin layer of water was used to couple ultrasound into the material. Using this approach, an ultrasonic contact surface C-scan inspection was performed. To facilitate the bond evaluation, a reference sample was made with two CMC facesheets bonded in three configurations: (i) bonded with adhesive (ii) dis-bonded without adhesive and (iii) dis-bonded with adhesive but in intimate contact. The results showed that using a combination of the amplitude and time-of-flight images the method can provide valuable information about the bond integrity. An independent X-ray CT scan on a small panel confirms a feature detected with this ultrasonic contact surface imaging technique. Using this approach, the bond integrity in the foam-based hybrid composite was evaluated.

WEDNESDAY

WEDNESDAY, JULY 23, 2014

	Session 16 **Guided Waves II-Modelling** ***Peregrines***	**Session 17** **Nuclear Reactors II** ***Cottonwoods-Firs***	**Session 18** **Uncertainty/Reliability of NDE** ***Pines-Willows***	**Session 19** **Nonlinear Ultrasonics** ***Salmon-Snake***
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12:10 PM	LUNCH			
	Session 20 **Guided Waves III** ***Peregrines***	**Session 21** **Composites I** ***Pines-Willows***	**Session 22** **Microstructure** ***Cottonwoods-Firs***	**Session 23** **Structural Health Monitoring** ***Salmon-Snake***
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Session 16

Wednesday, July 23, 2014

SESSION 16

GUIDED WAVES II-MODELLING

Peter Cawley and Ronald A. Roberts, Co-Chairpersons
Peregrines

8:30 AM **Numerical Analysis of Leaky Lamb Wave Propagation Using a Semi-Analytical Finite Element Method**
---**Takahiro Hayashi** and Daisuke Inoue, Kyoto University, Graduate School of Engineering, Kyoto, Japan

8:50 AM **Validation of Hybrid SAFE-FE Guided Wave Scattering Predictions in Rail**
---**Craig S. Long** and Philip W. Loveday, CSIR Materials Science and Manufacturing, Pretoria 0001, South Africa

9:10 AM **Feature-Guided Waves (FGW) in Plate Structures with 90 Degree Transverse Bends**
---**Zheng Fan** and Xudong Yu, School of Mechanical & Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore; Prabhakaran Manogaran and Prabhu Rajagopal, Center for Nondestructive Evaluation, Indian Institute of Technology Madras, Chennai 600036, Tamil Nadu, India

9:30 AM **Interaction of Lamb Waves with Geometric Discontinuities: An Analytical Approach**
---**Banibrata Poddar** and Victor Giurgiutiu, University of South Carolina, Department Mechanical Engineering, Columbia, SC 29208

9:50 AM **Guided Wave Simulation in Plates Using Split-Domain FEM Approach**
---**Sandeep Kumar S R**, Sri Harsha Reddy K, Krishnan Balasubramaniam, and Ganesan N, Indian Institute of Technology Madras, Centre for Non-destructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

10:10 AM ***Break***

10:30 AM **New Transparent Boundary Conditions for Time Harmonic Diffraction by a Localized Defect in Anisotropic Elastic Media**
---**Vahan Baronian** and Antoine Tonnoir, CEA-LIST-DISC, Gif-sur-Yvette, France; Anne Sophie Bonnet-Ben Dhia, Sonia Fliss, and Antoine Tonnoir, POEMS (CNRS-INRIA-ENSTA), ENSTA, Palaiseau, France

10:50 AM **Multi-Layered Anisotropic Media Generated with the Spectral Method**
---**Francisco Hernando Quintanilla** and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Richard Craster, Imperial College, Mathematics, London, United Kingdom

11:10 AM **Resonant Phenomena of Circumferential SH Waves Converted from T(0,1) Mode Guided Waves at Non-Axisymmetric Defect**
---**Hideo Nishino** and Saygo Ishii, The University of Tokushima, Institute of Technology and Science, Tokushima City, Tokushima Prefecture, Japan; Takashi Furukawa, Japan Power Engineering and Inspection Corporation, NDE Center, Yokohama City, Kanagawa Prefecture, Japan

11:30 AM **Optimal Computation of Guided Wave Propagation and Scattering in Pipeworks Comprising Elbows: Experimental and Numerical Validations and Parametric Studies**
---Marouane El Bakkali, **Alain Lhémery**, Bastien Chapuis, and Vahan Baronian, CEA, LIST, Gif-sur-Yvette, France; François Berthelot, CETIM, Nantes, France

11:50 AM **Separation of Applied Stress and Temperature Effects on an Ultrasonic Guided Wave Phase**
---**Oleg Lobkis**, Chris Larsen, and Richard Roth II, Etegent Technologies, Cincinnati OH 45212

12:10 PM ***Lunch***

8:30 AM

Numerical Analysis of Leaky Lamb Wave Propagation Using a Semi-Analytical Finite Element Method

---**Takahiro Hayashi** and Daisuke Inoue, Kyoto University, Graduate School of Engineering, Kyoto, Japan

---A semi-analytical finite element method (SAFE) has been widely used for analyzing guided waves because the special finite element analysis that does not require mesh division in the propagation direction enables us to perform efficient guided wave calculations even for large plate-like structures. Although many publications on the SAFE discussed guided waves in a bar with stress-free boundaries, guided wave attenuation due to energy leak into surrounding media such as air, water, and soil cannot be neglected in actual non-destructive inspection. This study discussed the SAFE calculation for leaky Lamb waves in a plate surrounded by fluid media. First we formulated the SAFE in a plate with leaky media using the fact that a wave number vector of a leaky wave is determined by a wave number of a Lamb wave mode and wave velocity in the leaky medium. Resulting third-order nonlinear eigenvalue problem were converted into a linear eigenvalue problem using characteristics of guided wave propagation and the solution provided wave number of leaky Lamb waves as well as Scholte wave that propagates between fluid - solid boundaries at about the same speed as wave velocity of the fluid. Dynamic responses were also derived for external loading on the plate surface and transient wave at arbitrary positions were calculated. This provides the animation of Lamb wave in the plate, leaky waves in the fluid and Scholte wave at the fluid - solid boundaries.

8:50 AM

Validation of Hybrid SAFE-FE Guided Wave Scattering Predictions in Rail
---**Craig S. Long** and Philip W. Loveday, CSIR Materials Science and Manufacturing, Pretoria 0001, South Africa

---Guided waves are well suited for structural interrogation of continuously welded rail track and are being exploited in a commercial monitoring system. This system consists of alternating transmit and receive stations spaced approximately 1km apart, and relies on a pitch-catch mode of operation to reliably detect complete breaks in the rail. Research efforts to extend this system to include a pulse-echo capability for detecting damage before complete breaks occur (while retaining the pitch-catch mode to ensure robustness) have recently been presented by the authors. This extension relies on the both numerical and experimental techniques to guide the development. A relatively simple transducer array was used to demonstrate that it is possible to detect reflections from welds 500m from the transducer in either direction in the field. An efficient hybrid SAFE-FE numerical method, capable of predicting reflections from arbitrary discontinuities, has also been implemented. This model has been used to develop quantitative predictions of power scattered from various crack and weld geometries for various incoming and reflected modes. The correctness of our numerical implementation has been verified by comparison with previously published results. In this paper, we will attempt to validate the hybrid SAFE-FE method, by comparison with both experimental and numerical results. Measurements of reflections from a weld and possibly a passive reflector bonded to a rail in the field will be used for comparison. A numerical comparison between the implemented frequency based method and a time domain explicit analysis, using the commercial finite element package ABAQUS, will also be performed for various crack geometries.---Financial support from the CSIR, the Department of Science and Technology and the National Research Foundation of South Africa are gratefully acknowledged.

9:10 AM

Feature-Guided Waves (FGW) in Plate Structures with 90 Degree Transverse Bends

---**Zheng Fan** and Xudong Yu, School of Mechanical & Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore; Prabhakaran Manogaran and Prabhu Rajagopal, Center for Nondestructive Evaluation, Indian Institute of Technology Madras, Chennai 600036, Tamil Nadu, India

---Ultrasonic guided waves are attractive for rapid remote screening of large structures and today they are widely used in several practical applications including the inspection of pipe and plate installations. More recently, guided wave modal solutions confined in extended local features have attracted much research interest, offering the possibility of inspecting difficult geometric or topographical features. Such 'feature-guided wave (FGW)' modes have been reported in plate waveguides with local cross-section variation or curvature, and in annular circular cylinders with cross-sectional anomalies. This paper focuses on FGW phenomena in 90 degree structural bends in plate structures, which commonly occur in various industrial structures. Modal studies are carried out using the Semi-Analytical Finite Element (SAFE) method, while 3D finite element (FE) simulations are used to gain visualization of results and also obtain cross-validation. Our studies reveal, perhaps for the first time, the possibility of bend-guided modes of the shear-horizontal (SH) family, in addition those of the Rayleigh-Lamb family reported earlier in the literature. This mode has attractive properties including low attenuation and limited dispersion. We investigate effects of plate thickness and bend radius on the physics of FGW in bends, arguing the strong role of geometry and curvature effects in causing mode confinement. The potential for applying bend-guided modes for the inspection of plate bends is also discussed.

9:30 AM

Interaction of Lamb Waves with Geometric Discontinuities: An Analytical Approach

---**Banibrata Poddar** and Victor Giurgiutiu, University of South Carolina, Department Mechanical Engineering, Columbia, SC 29208

---The non-destructive testing of materials can be conducted by various techniques. Among these, method based on ultrasonic waves is one of the most common one. Of these ultrasonic waves Lamb waves are of particular interest for the inspection of large structures for various reasons. Scattering of Lamb waves from flaws has generated a considerable amount of research over last couple of decades. Most of the work has been done using computational tools like Finite Element Methods and experimental technique. In this paper an analytical approach is presented to develop a fundamental understanding of the scattering of Lamb waves from geometric discontinuities in 2 dimensions. We have considered simplest of all geometric discontinuity – a step, as this fundamental understanding can easily be extended to corrosion or crack. However the analysis is complex as the scattered wave field is composed of infinite number of Lamb wave modes with variation along the thickness direction. This requires first to accurately compute the frequency spectrum of Lamb waves by solving the Rayleigh-Lamb equation in the complex domain. This was done by writing a solver to find the complex roots of the Rayleigh-Lamb equation using MATLAB. To calculate the scattered wave field we expressed the field in terms of the fundamental Lamb modes consisting of real, imaginary and complex wave numbers. Then we apply the stress and displacement boundary conditions at the location of discontinuity. Thus we get the equations of stress and displacements containing unknown amplitudes corresponding to large number of wave modes varying in the thickness direction. The solutions of the unknown amplitudes are obtained by projecting the boundary condition on eigen space of the fundamental modes. This allows us to take advantage of the complex reciprocity principle thereby obtaining a quicker convergence of the solution. Of these amplitudes we are only interested in the amplitudes of the modes having real wave numbers other modes represent local vibrations. Therefore quicker convergence with minimum number of modes is desirable. These solutions are then compared with axial-flexural waves at low frequencies where they should converge.

9:50 AM

Guided Wave Simulation in Plates Using Split-Domain FEM Approach
---**Sandeep Kumar S R**, Sri Harsha Reddy K, Krishnan Balasubramaniam, and Ganesan N, Indian Institute of Technology Madras, Centre for Non-destructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

---This paper reports the quantitative comparison of A-scans obtained from the simulations of fundamental guided wave modes in a plate by split-domain Finite Element Modelling approach with the more conventional single domain FEM method. Split Approach is the computationally efficient technique that has been developed for simulating long-range guided wave propagation in complex structures with limited computation resources. This Split Approach method involves sub-domain FE modelling which involves the splitting the larger FE model into smaller sub-domain models, solving them individually and finally transferring the wave from one sub-domain to the next sub-domain. In this paper simulations of guided wave propagation were carried out in a plate using ABAQUS® Explicit FE package. The results thus obtained were also compared to experiments conducted on illustrative plates with and without defects.

10:30 AM

New Transparent Boundary Conditions for Time Harmonic Diffraction by a Localized Defect in Anisotropic Elastic Media

---**Vahan Baronian** and Antoine Tonnoir, CEA-LIST-DISC, Gif-sur-Yvette, France; Anne Sophie Bonnet-Ben Dhia, Sonia Fliss, and Antoine Tonnoir, POEMS (CNRS-INRIA-ENSTA), ENSTA, Palaiseau, France

---Numerical methods dedicated to the modelling of Guided Wave (GW) diffraction have been studied and developed at CEA-LIST in order to enhance the capabilities of simulation in the CIVA software. These tools are based on the so-called Transparent Boundary Conditions (TBC) approach; but up today are limited to the case of elastic cylinders of arbitrary cross section (pipe, rail, beam). In this paper, we propose the baseline of an original method to simulate the diffraction of time harmonic GW by an arbitrary localized defect (cracks, cavities or inclusions) in an infinite anisotropic elastic plate. The difficulty is to find a way to restrict the finite element computational domain to a small box containing the defect with appropriate boundary conditions to properly take into account the outgoing wave condition in the radial direction. Classically, to simulate diffraction problems in unbounded domains, well known techniques such that Perfectly Matched Layers (PML) or radial TBC are often used. Unfortunately, both techniques failed in our situation. The new method proposed here can be explained as follow in the case of a 2D infinite anisotropic elastic media (transverse resonance is not taken into account). The whole domain is split into five subdomains: A square that surrounds the defect in which a classical finite element representation is used (to handle arbitrary defect) and four half planes leaning on the four edges of the square, in which analytical representations of the solution are derived. More precisely, the field in each half plane is related to its trace on the boundary, in an integral form. To close the system (involving the unknown in the square and the four unknowns on the boundaries of half planes), transmission relations are written between each unknowns to ensure the compatibility between the five representations. Numerical results in the case of 2D infinite anisotropic elastic plate will be presented, as well as the recent advances on the extension of this method to solve the diffraction problem in a 3D elastic anisotropic plate.

10:50 AM

Multi-Layered Anisotropic Media Generated With the Spectral Method
---**Francisco Hernando Quintanilla** and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Richard Craster, Imperial College, Mathematics, London, United Kingdom

---Guided waves are now well established in NDE and there is ongoing research interest in guided waves for many applications so it is important to have reliable and accurate information about the waves and modes that can be propagated in a chosen waveguide structure. Valuable information is provided by the dispersion curves of different modes within various combinations of geometries and materials. However, the approach normally used to find them, root-finding methods, suffers from certain limitations concerning geometry, type of material, ill-conditioning of the matrix used to derive the dispersion relation, the well-known "large-fd" problem and incomplete solutions (missing modes). In this paper we extend the Spectral Method, previously and successfully used in simple waveguide cases, to handle more complicated waveguide problems and show that all the above pitfalls and limitations are overcome by using this approach. All the cases presented deal with anisotropic homogeneous perfectly elastic materials in flat and cylindrical geometry. We also address the problem of multi-layered systems with both solid and fluid layers and the implementation of a spring model for imperfect boundary conditions between layers.

11:10 AM

Resonant Phenomena of Circumferential SH Waves Converted From T(0,1) Mode Guided Waves at Non-Axisymmetric Defect

---**Hideo Nishino** and Saygo Ishii, The University of Tokushima, Institute of Technology and Science, Tokushima City, Tokushima Prefecture, Japan; Takashi Furukawa, Japan Power Engineering and Inspection Corporation, NDE Center, Yokohama City, Kanagawa Prefecture, Japan

---Guided wave technique is an effective tool for monitoring integrity of piping. However, propagation phenomena of the guided waves at defects are not yet understood completely. Therefore, investigation of the phenomena from the many points of view must be important for more efficient and accurate guided wave measurements. In this paper, propagation behaviors of the T(0,1) mode guided waves at non-axisymmetric defects were considered with the FEM simulations, the theory and the experimental results. It was found that resonances of circumferential (C-) SH waves converted from the T(0,1) mode guided waves at non-axisymmetric defects occurred clearly for the specific frequencies. The standing waves of the C-SH waves were verified experimentally with the laser interferometer for detecting the distributions of the particle displacement speed along the girth. The FEM simulations were also underpinned the phenomena. The resonances were confirmed obviously on condition that the C-SH waves formed standing waves along the girth. Conversely, the resonances were not confirmed on condition that the other C-guided wave, namely the C-Lamb waves, formed the standing waves. In addition, the other T(0,1) mode guided waves that were originated from the resonant C-SH waves mode were confirmed while the resonances occurred.

11:30 AM

Optimal Computation of Guided Wave Propagation and Scattering in Pipeworks Comprising Elbows: Experimental and Numerical Validations and Parametric Studies
---Marouane El Bakkali, **Alain Lhémery**, Bastien Chapuis, and Vahan Baronian, CEA, LIST, Gif-sur-Yvette, France; François Berthelot, CETIM, Nantes, France

---Simulation tools of guided wave (GW) examination are developed at CEA to help to optimally conceive inspections and to interpret results. In a previous paper [1], i) the GW propagation in an elbow was modeled my means of an adaptation to curved guides of the semi-analytical finite element (SAFE) method, ii) the GW scattering at the junction between a straight and a curved guides, computed by means of an adapted mode-matching method, iii) GW multiple-scattering by an elbow joined to two straight pipes, computed by means of a method described in [2]. The aim of the present paper is twofold. First, the modeling approach is validated by comparison with results computed by the finite element method and by experimental measurements. Second, the model is used for parametric studies in this configuration, common in industrial pipeworks. Pulse-echo experiments were made on industrial pipes using a magnetostrictive patch to generate the torsional mode T(0,1). Comparisons with FE results of the literature concern torsional and longitudinal modes. In all cases, mode-conversions occurring at junctions must be accounted for. The method is computationally optimal and many results can be obtained by fast post-processing. Consider the case of elbows of various angles joined to straight pipes. Modes in the straight guide and those in the curved one are computed once by SAFE methods over the shared meshed cross-section. Scattering with mode-conversion at junction of straight and curved pipes requires computing once surface integrals over the same section for applying the mode-matching method. Then, the effect of elbow angle on scattering coefficients for the straight-curved-straight double junction requires only combining scattering matrices local to junctions with an analytic propagation matrix in the elbow of varying angle. Specific features of the reflection and transmission coefficients of this complex scatterer are exhibited. They may be helpful for choosing appropriate inspection configurations, notably, the frequency range to be used.

References:

1. M. El Bakkali, A. Lhémery, V. Baronian and F. Berthelot, “Guided wave propagation and scattering in pipeworks comprising elbows,” Rev. Prog. QNDE 33, (AIP Conf. Proc., Vol. 1581), pp. 332-339 (2014).
2. V. Baronian, A. Lhémery and K. Jezzine, “Hybrid SAFE/FE simulation of inspections of elastic waveguides containing several local discontinuities or defects,” Rev. Prog. QNDE 30, (AIP Conf. Proc., Vol. 1335), pp. 183-190 (2011).

11:50 AM

Separation of Applied Stress and Temperature Effects on an Ultrasonic Guided Wave Phase

---**Oleg Lobkis**, Chris Larsen, and Richard Roth II, Etegent Technologies, Cincinnati OH 45212

---A waveguide attached to a diaphragm in the wall of a high pressure and high temperature chamber can be used to estimate parameters inside it. If an ultrasonic wave is excited in the thin metal cylindrical waveguide, then its phase will change due to pressure variance in the chamber. Both the wire extension and acoustoelastic effect due to this extension should be taken into account. Unfortunately, temperature outside the chamber fluctuates as well and the guided wave velocity and the wire length and its thickness depend on it. As a result, a standard procedure cannot be used to separate an additional phase shift due to temperature from the phase change due to stress in the wire. The frequency dependence of the longitudinal L01 guided wave mode velocity on applied stress and temperature was investigated. It was found that due to uniaxial stress anisotropy and temperature isotropy the velocity dependences on frequency are different. It allows us to compensate temperature effects and use waveguides for applied stress measurement in fluctuating temperature environments.

Session 17

SESSION 17
NUCLEAR REACTORS II
S. W. Glass and Pradeep Ramuhalli, Co-Chairpersons
Cottonwoods-Firs

8:30 AM **Prognostic Health Monitoring Dry Cask Storage of Spent Nuclear Fuel**
---**Darryl P. Butt**, Vikram Patel, Mike Hurley, Sin Ming Loo, Jake Blanchard, Jack Ma, Kumar Sridharan, Sean McDevitt, and Howie Choset, Boise State University, Boise, ID 83726; Center for Advanced Energy Studies, Idaho Falls, ID; University of Wisconsin, Madison, WI; Carnegie Mellon University, Pittsburgh, PA 15201

9:10 AM **Meso-Scale Magnetic Signatures for Nuclear Reactor Steel Irradiation Embrittlement Monitoring**
---Pradeep Ramuhalli, Shenyang Y. Hu, Yulan Li, Weilin Jiang, Danny J. Edwards, Alan L. Schemer-Kohrn, Jonathan D. Suter, and Bradley R. Johnson, Pacific Northwest National Laboratory, Richland, WA; **John S. McCloy**, Washington State University, Pullman, WA 99163

9:30 AM **Study of Ultrasonic Characterization and Propagation in Austenitic Welds: The MOSAICS Project**
---**Bertrand Chassignole**, EDF R&D, MMC Department, Moret-sur-Loing, France; Patrick Recolin, DCNS/CESMAN, La Montagne, France; Nicolas Leymarie, CEA/LIST, Saclay, France; Cecile Gueudre, LCND-LMA, Aix-Marseille University, CNRS UPR 7051, France; Philippe Guy, INSA LYON, LVA Laboratory, Villeurbanne, France; Deborah Elbaz, EXTENDE, Massy, France

9:50 AM **Experimental Validation of an 8 Element EMAT Phased Array Probe for Longitudinal Wave Generation**
---**Florian Le Bourdais** and Benoît Marchand, CEA LIST, Centre de Saclay F-91191 Gif-sur-Yvette, France

10:10 AM ***Break***

10:30 AM **Eddy Current Signature Comparison Assures Correct Tube Identification**
---**Samuel W. Glass** and Ratko Vojvodic, AREVA NDE Solutions, 155 Mill Ridge Road, Lynchburg VA 24503

10:50 AM **Remote Controlled Vehicle for Inspection of Vertical Concrete Structures**
---Maria B. Guimaraes and **John T. Lindberg**, Electric Power Research Institute, Nuclear Sector - NDE Innovation, 1300 West WT Harris Blvd., Charlotte, NC 28262

11:10 AM **Progress Towards Developing Neutron Tolerant Magnetostrictive and Piezoelectric Transducers**
---Brian Reinhardt[1], **Bernhard Tittmann[1]**, Joy Rempe[2], Joshua Daw[2], Gordon Kohse[3], David Carpenter[3], Michael Ames[3], Yakov Ostrovsky[3], Pradeep Ramuhalli[4], Robert Montgomery[4], Hual Te Chien[5]; and B. Wernsman[6] [1]The Pennsylvania State University, 212 EES Building, University Park, PA 16802; [2]Idaho National Laboratory; [3]Mssachusetts Institute of Technology; [4]Pacific Northwest National Laboratory; [5]Argonne National Laboratory; [6]Bettis Bechtel Co

11:30 AM **Designing a TAC Thermometer from a VHTR Graphite Structure**
---**James A. Smith** and Dale Kotter, Idaho National Laboratory, Fuel Performance and Design, Idaho Falls, ID 83415-6188; Steven L. Garrett and Randall A. Ali, Penn State University, Graduate Program in Acoustics, State College, PA 16801

11:50 AM **Inspection of Fuel Rod Crud Using Optical Coherence Tomography**
---Jeremy Renshaw[1], **Tom Jenkins[2]**, Ben Buckner[2], and Brian Friend[3], [1] Electric Power Research Institute, Charlotte, NC 28262; [2] MetroLaser, Inc., Laguna Hills, CA 92653; [3] AREVA, Inc., Lynchburg, VA 24505

12:10 PM ***Lunch***

8:30 AM

Prognostic Health Monitoring Dry Cask Storage of Spent Nuclear Fuel

---**Darryl P. Butt**, Vikram Patel, Mike Hurley, Sin Ming Loo, Jake Blanchard, Jack Ma, Kumar Sridharan, Sean McDevitt, and Howie Choset, Boise State University, Boise, ID 83726; Center for Advanced Energy Studies, Idaho Falls, ID; University of Wisconsin, Madison, WI; Carnegie Mellon University, Pittsburgh, PA

---On-site storage of spent nuclear fuel (SNF) at reactor sites was intended to be a relatively short term, interim stage of the U.S. plan for long-term storage and disposition of nuclear waste. However, in the absence of a permanent, central repository for spent nuclear fuel or reprocessing scheme in the U.S. has necessitated longer-term storage of spent nuclear fuel on-site or at distributed Independent Spent Fuel Storage Installations (ISFSIs). Regulations for ISFSIs for the initial storage period up to 20 years with the potential for an extension of an additional 20 years were given in 1998. Until a permanent solution is determined through policy enactment, dry storage is effectively the current final stage of the life-cycle of nuclear reactor fuel in the U.S. Consequently, in order to address the potential issues associated with onsite, dry storage, the NRC and DOE, in cooperation with organizations such as EPRI as well as national laboratories, universities and the various vendors, have attempted to identify and characterize expected degradation modes of the fuel and containment materials at times beyond 20 years. Validation of models and stewardship of SNF, in addition to maintaining public confidence, requires tools for and a science-based approach to surveillance and prognostic health monitoring of spent nuclear fuel storage. Here we describe methods for developing sensing and delivery technologies to enhance the safety, confidence, science-based assessment of dry cask storage of spent nuclear fuel (SNF) using a robotic technology for use in inspections and sensor delivery, radiation and environmentally durable real time sensors and analyses, and secure data communications. We will describe compact systems for prognostic health monitoring of spent nuclear fuel storage, with much of the focus on assessing the weld integrity in the inner cask and environmental conditions for corrosion and stress corrosion cracking.

9:10 AM

Meso-Scale Magnetic Signatures for Nuclear Reactor Steel Irradiation Embrittlement Monitoring

---Pradeep Ramuhalli, Shenyang Y. Hu, Yulan Li, Weilin Jiang, Danny J. Edwards, Alan L. Schemer-Kohrn, Jonathan D. Suter, and Bradley R. Johnson, Pacific Northwest National Laboratory, Richland, Washington; **John S. McCloy**, Washington State University, Pullman, Washington

---Verifying the structural integrity of passive components in light-water and advanced reactors will be necessary to ensure safe, long-term operations of the existing U.S. nuclear fleet. This objective can be achieved through nondestructive condition monitoring techniques, which can be integrated with plant operations to quantify the 'state of health' of structural materials in real-time. While nondestructive methods for monitoring many classes of degradation (such as fatigue or stress corrosion cracking) are relatively advanced, this is not the case for degradation because of irradiation. The development of NDE technologies for these types of degradation will require advanced materials characterization techniques and tools that enable comprehensive understanding of nuclear reactor material microstructural and behavioral changes under extreme operating environments. Irradiation-induced degradation of reactor steels causes changes in their micro-magnetic properties. One example is the irradiation-induced formation of Cr precipitates that have been observed in Fe-Cr-Ni steels. These precipitates cause changes in bulk magnetic NDE signatures (e.g., major and minor hysteresis loops). We hypothesize that these property changes can be measured using micro-magnetic methods. We also assert that phase field computational methods can be used to create meso-scale microstructural models that can represent both the radiation damage and predict its impact on magnetic signatures. In this paper, we describe preliminary results to integrate advanced materials characterization techniques with meso-scale computational models to provide an interpretive understanding of the state of degradation in a material. Microstructural measurements along with meso-scale magnetic measurements on ion-irradiated thin films are used to gain insights into the microstructural state and their impact on magnetic properties. Microstructural data are presented from monocrystalline and polycrystalline Fe before and after irradiation, and are correlated with variable-field magnetic force microscopy and micro-magnetic measurements. Preliminary conclusions from these correlations are presented, and next steps described.

9:30 AM

Study of Ultrasonic Characterization and Propagation in Austenitic Welds: The MOSAICS Project

---**Bertrand Chassignole**, EDF R&D, MMC Department, Moret-sur-Loing, France; Patrick Recolin, DCNS/CESMAN, La Montagne, France; Nicolas Leymarie, CEA/LIST, Saclay, France; Cecile Gueudre, LCND-LMA, Aix-Marseille University, CNRS UPR 7051, France; Philippe Guy, INSA LYON, LVA Laboratory, Villeurbanne, France; Deborah Elbaz, EXTENDE, Massy, France

---Regulatory requirements enforce a volumetric inspection of welded components of nuclear equipment. However, the multi-pass austenitic welds are characterized by anisotropic and heterogeneous structures which lead to numerous disturbances of the ultrasonic beam. The MOSAICS project supported by the ANR (French National Research Agency) aims at matching various approaches to improve the prediction of the ultrasonic testing in those welds. The first stage consists in characterizing the weld structure (measurements of elastic constants and attenuation coefficients and determination of the columnar grain orientation with image processing tools or MINA model). The techniques of characterization provide input data for the modeling codes developed in another task of the project. For example, a 3D version of the finite elements code ATHENA is developed by EDF R&D to take into account anisotropic texture in any direction. Semi-analytical models included in CIVA software are also improved to better predict the ultrasonic propagation in highly anisotropic and heterogeneous structures. The last stage deals with modeling codes validation based on experimental inspections on representative mock-ups containing calibrated defects. The objective of this paper is to give an overview of the MOSAICS project and to present specific results illustrating the various tasks.

9:50 AM

Experimental Validation of an 8 Element EMAT Phased Array Probe for Longitudinal Wave Generation
---**Florian Le Bourdais** and Benoît Marchand, CEA LIST, Centre de Saclay F-91191 Gif-sur-Yvette, France

---Sodium cooled fast reactors (SFR) use liquid sodium as a coolant. Liquid sodium being opaque, optical techniques cannot be applied to reactor vessel inspection. This makes it necessary to develop alternative ways of assessing the state of the structures immersed in the liquid [1]. Ultrasonic pressure waves are thus well suited to be used for inspection tasks in this medium, especially using pulsed electromagnetic acoustic transducers [2] (EMAT) that generate the ultrasound directly in the liquid sodium. The work carried out at CEA LIST is aimed at developing phased array EMAT probes conditioned for reactor use [3]. The present work focuses on the experimental validation of a newly manufactured 8 element probe, which was designed for beam forming imaging in a liquid sodium environment. First laboratory tests on an aluminum block show that the probe has the required beam steering capabilities.

References:
1. F. Baqué, J.-M. Augem, J. Sibilo, and F. Reverdy, “Development of Tools, Instrumentation and Codes for Improving Periodic Examination and Repair of SFRs,” Sci. Technol. Nucl. Install., vol. 2012, May 2012.
2. H. M. Frost, Electromagnetic-ultrasound transducers: principles, practice, and applications. Academic Press, 1979.
3. F. Le Bourdais and B. Marchand, “Design of EMAT Phased Arrays for SFR Inspection,” in Proceedings of the Review of Progress in Quantitative NDE Baltimore, USA, 2013.

10:30 AM

Eddy Current Signature Comparison Assures Correct Tube Identification
---**Samuel W. Glass** and Ratko Vojvodic, AREVA NDE Solutions, 155 Mill Ridge Road, Lynchburg Virginia, 24503

---Inspection of nuclear power plant steam generator tubes is required to justify continued safe plant operation. The steam generators consist of thousands of tubes with nominal diameters of 15 to 22mm, approximately 1mm wall thickness, and 20 to 30m in length. The tubes are inspected by passing an eddy current probe through the tubes from tube end to tube end. It is critical to know exactly which tube identification (row and column) is associated with each tube's data. This is controlled by a precision manipulator that provides the tube ID to the eddy current system. Historically however there have been some instances where the manipulator incorrectly reported the tube ID. This can have serious consequences including lack of inspection of a tube, or repairing the wrong tube and leaving the defective tube in service if the repairable indication is associated with the wrong tube ID thereby risking a primary to secondary leak. Eddy current inspection of the steam generator tubing is a mature examination that is driven by detailed EPRI guidelines. In response to an industry history of a small percentage of mis-encoded tubes, the EPRI guidelines recommend having redundant tube-ID verification. Traditionally this is accomplished with encoding provided by the inspection robot returning its position plus by an independent machine-vision system. This paper describes a tube ID fingerprinting approach that compares the current tube-sheet ET data signature with the historical tube-sheet ET data signatures. Performance was demonstrated in the field where the position was successfully verified on over 30,000 tubes. In all but 5 cases, the computer algorithms uniquely identified each tube based on its historical data. In these 5cases where the computer algorithm was inconclusive yet above the level where the mis-encode would be pronounced, the eddy current analyst could readily identify the correct tube. The obvious advantage of this approach is that it uses the ET data directly without any additional robotic equipment. The method has been successfully applied on numerous inspections since its first implementation in 2010.

10:50 AM

Remote Controlled Vehicle for Inspection of Vertical Concrete Structures
---Maria B. Guimaraes and **John T. Lindberg**, Electric Power Research Institute, Nuclear Sector - NDE Innovation, 1300 West WT Harris Blvd., Charlotte, NC 28262

---The infrastructure in the energy industry includes several types of large, curved vertical structures such as cooling towers, nuclear containments and hydroelectric dams. Inspections of these structures are often performed manually by means of scaffolds. Automating such inspections will reduce time and costs, make them more efficient, increase inspection frequency and reduce personnel and industrial safety risks. To address this inspection need, EPRI evaluated different types of robotics technologies and their technology readiness level and concluded with the selection of a device that could be adapted to a variety of needs. The device identified did not include a positioning system or a nondestructive examination (NDE) device, which were integrated into the crawler by modifying existing technologies. During the fall of 2012, an initial demonstration took place of the crawling device with the mapping and positioning system and an attached air-coupled NDE device. Following this demonstration, improvements were made in the integration of positioning system and NDE technology, and the crawler performed a limited scope inspection demonstration in July 2013 at a major hydrodam facility located in the United States. Two more demonstration deployments are being planned for 2014. The concrete crawler will support long-term operation of generating assets by enabling fast, safe, and in-depth inspection of structures such as cooling towers, hydro dams, and reactor containments. It will obviate the need to use scaffolding or rappelling for routine structural evaluations, eliminating the associated setup challenges, time requirements, costs, and safety hazards. This will help avoid the critical path for inspections that must be performed during nuclear plant outages. Its payload of advanced NDE instrumentation will provide unprecedented abilities to interrogate the interior of concrete structures and locate and characterize voids, rebar corrosion, and other internal defects. Computer-encoded data and images will support real-time condition assessment and long-term monitoring of degradation and aging processes to guide maintenance decision-making and risk-informed management for nuclear, fossil, and hydro assets. This presentation highlights the technology searching process for a suitable device, the development, and provides an update on demonstrations of its capabilities. Videos are available that highlight the demonstrations.

11:10 AM

Progress Towards Developing Neutron Tolerant Magnetostrictive and Piezoelectric Transducers

---Brian Reinhardt[1], **Bernhard Tittmann**[1], Joy Rempe[2], Joshua Daw[2], Gordon Kohse[3], David Carpenter[3], Michael Ames[3], Yakov Ostrovsky[3], Pradeep Ramuhalli[4], Robert Montgomery[4], Hual Te Chien[5]; B. Wernsman[6] [1]The Pennsylvania State University, 212 EES Building, University Park, PA 16802; [2]Idaho National Laboratory; [3]Mssachusetts Institute of Technology; [4]Pacific Northwest National Laboratory; [5]Argonne National Laboratory; [6]Bettis Bechtel Co

---Current generation light water reactors (LWRs), sodium cooled fast reactors (SFRs), small modular reactors (SMRs), and next generation nuclear plants (NGNPs) produce harsh environments in and near the reactor core that can severely tax material performance and limit component operational life. To address this issue, several Department of Energy Office of Nuclear Energy (DOE-NE) research programs are evaluating the long duration irradiation performance of fuel and structural materials used in existing and new reactor designs. In order to maximize the amount of information obtained from Material Testing Reactor (MTR) irradiations, DOE is also funding development of enhanced instrumentation that will be able to obtain in-situ, real-time data on key material characteristics and properties, with unprecedented accuracy and resolution. Such data are required to validate new multi-scale, multi-physics modeling tools under development as part of a science-based, engineering driven approach to reactor development. It is not feasible to obtain high resolution/microscale data with the current state of instrumentation technology. However, ultrasound-based sensors offer the ability to obtain such data if it is demonstrated that these sensors and their associated transducers are resistant to high neutron flux, high gamma radiation, and high temperature. To address this need, the Advanced Test Reactor National Scientific User Facility (ATR-NSUF) is funding an irradiation, led by the Pennsylvania State University (PSU), at the Massachusetts Institute of Technology Research Reactor to test the survivability of ultrasound transducers. As part of this effort, PSU and collaborators have designed, fabricated, and provided piezoelectric and magnetostrictive transducers that are optimized to perform in harsh, high flux environments.[1,2] Four piezoelectric transducers were fabricated with aluminum nitride, zinc oxide, and bismuth titanate as the active element. The transducers are coupled to kovar and aluminum waveguides of which pulse-echo ultrasonic measurements are made in-situ. Two magnetostrictive transducers were fabricated with Remendur and Galfenol as the active elements. These devices will be pulsed and monitored in-situ. This paper will present an overview of the test design including selection criteria for candidate materials and optimization of test assembly parameters, data obtained from both out-of-pile and in-pile testing at elevated temperatures, and an assessment based on initial data of the expected performance of ultrasonic devices in irradiation conditions.---The authors are grateful for the support of the ATR-NSUF grant No. 132366.

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1. Rempe, J. L, MacLean, H., Schley, R., Hurley, D., Daw, J., Taylor, S., Smith, J., Svoboda, J., Kotter, D., Knudson, D., Guers, M., SC Wilkins, S. C., and Bond, L. J. (2011). “Strategy for Developing New In-pile Instrumentation to Support Fuel Cycle Research and Development”. INL/EXT-10-19149, Idaho National Laboratory, Idaho Falls, Idaho.
2. Parks, D. A., Reinhardt, B., and Tittmann, B. R. (2012)."Piezoelectric Material for use in a Nuclear Reactor Core", in Review of Progress in Quantitative Nondestructive Evaluation, Vols. 31a and 31b, edited by D. O. Thompson and D. E. Chimenti Vol. 1430, pp. 1633-1639.

11:30 AM

Designing a TAC Thermometer from a VHTR Graphite Structure
---**James A. Smith** and Dale Kotter, Idaho National Laboratory, Fuel Performance and Design, Idaho Falls, ID 83415-6188; Steven L. Garrett and Randall A. Ali, Penn State University, Graduate Program in Acoustics, State College, PA 16801

---The interior of a nuclear reactor presents a particularly harsh and challenging environment for both sensors and telemetry due to high temperatures and high fluxes of energetic and ionizing particles among the radioactive decay products. Very High Temperature Reactors (VHTR) are pushing the in core temperatures even higher. A unique sensing approach will be discussed to address the necessary high temperature measurements. Thermoacoustic thermometry exploits high temperatures and uses materials that are immune to the effects of ionizing radiation to create a temperature sensor that is self-powered and wireless. In addition, the form-factor for the Thermoacoustic Thermometer (TACT) can be designed to be integrated within common in-pile structures. There are no physical moving parts required for TACT and the sensor is self-powered, as it uses the nuclear fuel for its heat source. TACT data will be presented from a laboratory prototype mimicking the design necessary for a VHTR graphite structure. To reliably test materials at high temperatures and radiation fluxes, requires a robust sensor that can take the "heat." The conundrum of how to develop a sensor from materials that can survive the environment and yet maintain transduction capabilities with minimal confounding influences can be greatly simplified by using the structural materials under test as a component in the transducer. The question which we are attempting to answer: Is it possible to implement a wireless self-powered sensor from structural materials used within the reactor while taking advantage of the harsh operating environment of the nuclear environment?---The funding for this work came from the US Department of Energy office of Nuclear Energy which oversees the Fuel Cycle Research and Development program.

11:50 AM

Inspection of Fuel Rod Crud using Optical Coherence Tomography

---Jeremy Renshaw[1], **Tom Jenkins**[2], Ben Buckner[2], and Brian Friend[3], [1] Electric Power Research Institute, Charlotte, NC 28262; [2] MetroLaser, Inc., Laguna Hills, CA 92653; [3] AREVA, Inc., Lynchburg, VA 24505

---Nuclear power plants regularly inspect fuel rods to ensure safe and reliable operation. Excessive corrosion can cause fuel failures which can have severe repercussions for the plant, including impacts on plant operation, worker exposure to radiation, and the plant's INPO rating. While plants typically inspect for fuel rod corrosion using eddy current techniques, these techniques have known issues with reliability in the presence of tenacious, ferromagnetic crud layers that can deposit during operation, and the nondestructive evaluation (NDE) inspection results can often be in error by a factor of 2 or 3. For this reason, alternative measurement techniques, such as Optical Coherence Tomography (OCT), have been evaluated that are not sensitive to the ferromagnetic nature of the crud. OCT has shown significant potential to characterize the thickness of crud layers that can deposit on the surfaces of fuel rods during operation. Physical trials have been performed on simulated crud samples, and the resulting data show an apparent correlation between the crud layer thickness and the OCT signal.

Session 18

SESSION 18
UNCERTAINTY OF NDE
Amanda Criner and Eric Lindgren, Co-Chairpersons
Pines-Willows

8:30 AM **Stochastic Inverse Problems: Models and Metrics**
---Elias H. Sabbagh, R. Kim Murphy, and **Harold A. Sabbagh**, Victor Technologies, LLC, P.O. Box 7706, Bloomington, IN 47407-7706; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, 36 Governors Court, Palm Beach Gardens, FL 33418; Jeremy S. Knopp, AFRL/RXCA, Wright Patterson AFB OH 45433-7817

8:50 AM **Assessing Inversion Performance and Uncertainty in Eddy Current Crack Characterization Applications**
---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, Victor Technologies LLC, Bloomington, IN; Charles Annis, Statistical Engineering, Palm Beach Garden, FL; Eric Shell, Wyle, Dayton, OH; Jeremy S. Knopp and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433

9:10 AM **Forward Propagation of Parametric Uncertainties Through Models of NDE Inspection Scenarios**
---**Matthew Cherry**[1], Harold Sabbagh[2], John Aldrin[3], and Jeremy Knopp[1], [1]Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB OH 45433-7817; [2]Victor Technologies, Bloomington, IN 47407-7706; [3]Computational Tools, Gurnee, IL 60031

9:30 AM **Toward Automated Interpretation of Integrated Information: Managing "Big Data" for NDE**
---**Elizabeth D. Gregory**, Tyler J. Lesthaeghe, and Stephen D. Holland, Iowa State University, Department of Aerospace Engineering and Center for NDE, Ames, IA 50011

9:50 AM **Identification of Thermal Degradation Using Probabilistic Models in Reflectance Spectroscopy**
---**Amanda K. Criner**, Adam T. Cooney, Tranton D. Katter, Aaron J. Cherry, H. T. Banks, Shuhua Hu, and Jared Catenacci, UDRI, 300 College Park, Dayton, OH 45469-0020

10:10 AM ***Break***

RELIABILITY OF NDE
David S. Forsyth and Daniel Kanzler, Co-Chairpersons

10:30 AM **On a Framework for Generating POD Curves Assisted by Numerical Simulations**
---**Subair S. Mohamed**, Shweta Agrawal, Krishnan Balasubramaniam, and Prabhu Rajagopal, Indian Institute of Technology Madras, Department of Mechanical Engineering, Chennai, T.N., India; Anish Kumar, Purnachandra B. Rao, and Jayakumar Tamanna, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, T.N., India

10:50 AM **Life Assessment Using Ultrasound SAFT and Computational Fracture Mechanics**
---**Xuefei Guan** and Kevin S. Zhou, Siemens Corporation, Corporate Technology, Princeton, NJ 08540; Wen Jiang, Duke University, Durham, NC; El Mahjoub Rasselkorde and Waheed A. Abbasi, Siemens Energy Inc., Pittsburgh, PA 15201

11:10 AM **Combining of Different Data Pools for Calculating a Reliable POD for Real Defects**
---**Daniel Kanzler** and Christina Müller, BAM Federal Institute for Materials Testing and Research; Berlin, Germany; Jorma Pitkänen, Posiva Oy, Eurajoki, Finland

11:30 AM **Simulated Probability of Detection Maps in Case of Non-Monotonic EC Signal Response**
---**Pierre Calmon**, Frédéric Jenson, and Christophe Reboud, CEA, LIST, Département Imagerie Simulation pour le Contrôle, 91191 Gif-sur-Yvette, France

11:50 AM **Lamb Wave-Based Damage Quantification and Probability of Detection Modeling for Fatigue Life Assessment of Riveted Lap Joints**
---**Jingjing He**, Dengjiang Wang, and Weifang Zhang, School of Reliability and System Engineering, Beihang University, Beijing, China

12:10 PM ***Lunch***

8:30 AM

Stochastic Inverse Problems: Models and Metrics
---Elias H. Sabbagh, R. Kim Murphy, and **Harold A. Sabbagh**, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, 36 Governors Court, Palm Beach Gardens, FL 33418; Jeremy S. Knopp, Air Force Research Laboratory (AFRL/RXCA), Wright Patterson AFB OH 45433-7817

---In past work, we introduced model-based inverse methods, and applied them to problems in which the anomaly could be reasonably modeled by simple canonical shapes, such as rectangular solids. In these cases the parameters to be inverted would be length, width and height, as well as the occasional probe lift-off or rotation. We are now developing a formulation that allows more flexibility in modeling complex flaws. The idea consists of expanding the flaw in a sequence of basic functions, and then solving for the expansion coefficients of this sequence, which are modeled as independent random variables, uniformly distributed over their range of values. There are a number of applications of such modeling: 1. Connected cracks and multiple half-moons, which we have noted in a POD set. Ideally we would like to distinguish connected cracks from one long shallow crack; 2. Cracks of irregular profile and shape which have appeared in cold work holes during bolt-hole eddy-current inspection. One side of such cracks is much deeper than other; 3. L or C shaped crack profiles at the surface, examples of which have been seen in bolt-hole cracks. By formulating problems in a stochastic sense, we are able to leverage the stochastic global optimization algorithms in NLSE, which is resident in VIC-3D, to answer questions of global minimization and to compute confidence bounds using the sensitivity coefficient that we get from NLSE. We will also address the issue of surrogate functions which are used during the inversion process, and how they contribute to the quality of the estimation of the bounds.

8:50 AM

Assessing Inversion Performance and Uncertainty in Eddy Current Crack Characterization Applications

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, Victor Technologies LLC, Bloomington, IN; Charles Annis, Statistical Engineering, Palm Beach Garden, FL; Eric Shell, Wyle, Dayton, OH; Jeremy S. Knopp and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH

---When performing inverse-methods for characterization of cracks, there is a need to assess the quality of the result without a priori knowledge of the flaw state. From the residual error between the model fit and the experimental data, and the sensitivity of the model to variation in the parameters in the neighborhood of the solution (the Jacobian), confidence intervals on the parameter estimates can be generated. In this presentation, several demonstrations will be given of evaluating confidence intervals for eddy current inverse methods and compared with known conditions. In practice, these metrics are useful but far from perfect. For example, this evaluation can produce very large intervals when a 'constraint' is met in the parameter space. There is another issue when performing an inversion, the possibility of getting caught in a local minima during the parameter estimation process. Various stochastic inverse methods have been proposed to overcome this challenge. Ideally, one would like to report the likelihood that the 'global' solution was achieved. A proposed metric here estimates the percentage of 'getting caught in local minima' using Monte Carlo simulations. One challenge that must be addressed is that for some eddy current inversions of 2D raster scan data, it may be difficult to get many repeated model calls due to computational time. While the vast majority of inversions in this study converged well to global solutions, some examples will be presented of inverting weaker signals, where the results may converge to different values for repeated inversions. Leveraging prior information can help constrain the problem and Bayesian methods can be quite beneficial. Going forward, the reporting of parameter confidence intervals and the likelihood that the global solution is achieved, is proposed for all eddy current inversion applications. Lastly, there are opportunities to assess and quantify any discrepancies that might occur during the calibration process. The evaluation and propagation of uncertainty due to calibration error will be considered for inverse methods. Ideally, process controls should be put in place to ensure the probe meets the expected response necessary to accurately size cracks. An adaptive inversion scheme may also be an option, for example to address certain levels of varying probe conditions.

9:10 AM

Forward Propagation of Parametric Uncertainties Through Models of NDE Inspection Scenarios

---**Matthew Cherry**[1], Harold Sabbagh[2], John Aldrin[3], Jeremy Knopp[1], [1]Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB OH 45433-7817; [2]Victor Technologies, Bloomington, IN 47407-7706; [3]Computational Tools, Gurnee, IL 60031

---Forward uncertainty propagation has been a topic of interest to NDE researchers for several years. To this point, the purpose has been to gain an understanding of the uncertainties that can be seen in signals from NDE sensors given uncertainties in the geometric and material parameters of the problem. However, a complex analysis of an inspection scenario with high variability has not been performed. Furthermore, these methods have not seen direct practical application in the areas of model assisted probability of detection or inverse problems. In this paper, we will describe the progress on this front made over the last ten years and give ideas for how these methods could see use in application areas not yet explored. Their connection to inverse uncertainty quantification will be drawn in several ways, and their application in the areas of multiscale modeling will be discussed as well. Examples will be provided that illustrate the effect of high variability in uncertainty propagation in the context of forward modeling.

9:30 AM

Toward Automated Interpretation of Integrated Information: Managing "Big Data" for NDE

---**Elizabeth D. Gregory**, Tyler J. Lesthaeghe and Stephen D. Holland, Iowa State University, Department of Aerospace Engineering and Center for NDE, Ames, IA 50011

---Large scale automation of NDE processes is rapidly maturing, thanks to recent improvements in robotics and the rapid growth of computer power over the last twenty years. It is fairly straightforward to automate NDE data collection itself, but the process of NDE remains largely manual. We will discuss three threads of technological needs that must be addressed before we are able to perform automated NDE. Spatial context, the first thread, means that each NDE measurement taken is accompanied by metadata that locates the measurement with respect to the 3D physical geometry of the specimen. In this way, the geometry of the specimen acts as a database key. Data context, the second thread, means that we record why the data was taken and how it was measured in addition to the NDE data itself. We will present our software tool that helps users interact with data in context, Databrowse. Condition estimation, the third thread, is maintaining the best possible knowledge of the condition (serviceability, degradation, etc.) of an object or part. In the NDE context, we can prospectively use Bayes' Theorem to integrate the data from each new NDE measurement with prior knowledge. These tools, combined with robotic measurements and automated defect analysis, will provide the information needed to make high-level life predictions and focus NDE measurements where they are needed most.

9:50 AM

Identification of Thermal Degradation Using Probabilistic Models in Reflectance Spectroscopy

---**Amanda K. Criner**[2], Adam T. Cooney[1], Tranton D. Katter[3], Aaron J. Cherry[4], H. T. Banks[5], Shuhua Hu[5], and Jared Catenacci[5], [1]Materials State Awareness & Supportability Branch, Air Force Research Lab, WPAFB, OH 45433; [2]University of Dayton Research Institute, Dayton, OH 45469; [3]Universal Technologies Corporation, Dayton, OH 45432; [4]Southwestern Ohio Council for Higher Education, Dayton, OH 45420; [5]Center for Research in Scientific Computation, North Carolina State University, Raleigh, NC 27695

---Different probabilistic models of molecular vibration modes are considered to model the reflectance spectra of chemical species through the dielectric constant. Probability measure estimators in parametric and nonparametric models will be considered. Analyses of ceramic matrix composite samples that have been heat treated for different amounts of times will be presented. These results will be compared with the analysis of vitreous silica using nonparametric models.

10:30 AM

On a Framework for Generating PoD Curves Assisted by Numerical Simulations
---**Subair S. Mohamed**, Shweta Agrawal, Krishnan Balasubramaniam, and Prabhu Rajagopal, Indian Institute of Technology Madras, Department of Mechanical Engineering, Chennai, T.N., India; Anish Kumar, Purnachandra B. Rao, and Jayakumar Tamanna, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, T.N., India

---The Probability of Detection (PoD) curve method has emerged as an important tool for the assessment of the performance of NDE techniques, a topic of particular interest to the nuclear industry where inspection qualification is very important. The conventional experimental means of generating PoD curves though, can be expensive, requiring large data sets (covering defects and test conditions), plant shut-down and also operator time. Several methods of achieving faster estimates for PoD curves using physics-based modelling have been developed to address this problem. Numerical modelling techniques are also attractive, especially given the ever increasing computational power available to scientists today. Here we develop procedures for obtaining PoD curves, assisted by numerical simulation and based on Bayesian statistics. Numerical simulations are performed using Finite Element analysis for factors which are assumed to be independent, random and normally distributed. PoD curves so generated are compared with experiments on SS plates with artificially created notches. We examine issues affecting the PoD curve generation process including codes, standards, distribution of defect parameters and the choice of the noise threshold. We also study the assumption of normal distribution for signal response parameters and consider strategies for dealing with data that may be more complex or sparse to justify this. These topics are addressed and illustrated through the example case of generation of PoD curves for pulse-echo ultrasonic inspection of vertical surface-breaking cracks in stainless steel (SS) plates.

10:50 AM

Life Assessment Using Ultrasound SAFT and Computational Fracture Mechanics
---**Xuefei Guan** and Kevin S. Zhou, Siemens Corporation, Corporate Technology, Princeton, NJ 08540; Wen Jiang, Duke University, Durham, NC; El Mahjoub Rasselkorde and Waheed A. Abbasi, Siemens Energy Inc., Pittsburgh, PA

---This paper presents a highly accurate life assessment methodology of critical components subject to fatigue damage. The methodology consists of flaw characterization using ultrasonic synthetic aperture focusing (SAFT) technique and damage evolution prediction using the finite element method. A three-dimensional SAFT reconstruction algorithm is used to provide flaw information such as geometry and orientation. The resulting flaw information is represented as a surface mesh. The surface mesh is then incorporated to the finite element-based fracture mechanics computational framework. To evaluate arbitrarily shaped crack, extended finite element method is employed to compute the stress intensity factor of the crack front and crack propagation under a given loading profile. The overall method is demonstrated using an application example. The advantage of the proposed method is highlighted.

11:10 AM

Combining of Different Data Pools for Calculating a Reliable POD for Real Defects
---Daniel Kanzler and Christina Müller, BAM Federal Institute for Materials Testing and Research; Berlin, Germany; Jorma Pitkänen, Posiva Oy, Eurajoki, Finland

---Real defects are essential for the evaluation of the reliability of non destructive testing (NDT) methods, especially in relation to the integrity of components. But in most of the cases the amount of available real defects is not sufficient to evaluate the system. Model-assisted and transfer functions are one way to handle that challenge. This study is focused on a combination of different data pools to create a sufficient amount of data for the reliability estimation. A widespread approach for calculating the Probability of Detection (POD) was used on a radiographic testing (RT) method. The highest contrast to noise ratio (CNR) of each indication is usually selected as the signal in the "â vs. a" (signal-response) approach for RT. By combining real and artificial defects (flat bottom holes, side drill holes, flat bottom squares, notches, etc) in RT the highest signals are close to each other, but the process of creating and evaluating real defects is much more complex. The solution is seen in the combination of real and artificial data using a weighted least square approach. The weights for real or artificial data were based on the importance, the value and the different detection behavior of the different data. For comparison, the alternative combination through the Bayesian Updating was also applied. As verification, a data pool with a large amount of real data was available. In an advanced approach for evaluating the digital RT data, the size of the indication (perpendicular to the X-ray beam) was introduced as additional information. The signal now consists of the CNR and the area of the indication. The detectability is changing depending on the area of the indication, a fact that was ignored in the previous POD calculations for RT. This points out that a weighted least square approach to pool the data might no longer be adequate. The Bayesian Updating of the estimated parameters of the relationship between the signal field (the area of the indication) and the geometry of the defects is seen as the appropriate model to combine the different defect types in a useful and meaningful way.---This work was carried out together with the Finnish company for spent nuclear fuel and waste management – Posiva Oy. The digital RT is one of the NDT methods that might be used for the inspection of the weld of the copper canister to be used for the spent nuclear fuel in the Scandinavian concept of final disposal.

11:30 AM

Simulated Probability of Detection Maps in Case of Non-Monotonic EC Signal Response

---**Pierre Calmon**, Frédéric Jenson, and Christophe Reboud, CEA, LIST, Département Imagerie Simulation pour le Contrôle, 91191 Gif-sur-Yvette, France

---The empirical estimation of Probability of detection curves, based on experimental data gathered through expensive and cumbersome round-robin processes, is now a well-established practice in several industrial domains, like Aeronautics [1]. Starting from these sets of data, a standard procedure [2] consists in assuming a given functional form of the POD curve, like a cumulative log-normal one, which parameters are fitted to the data set. This assumption relies on the fact that the signal response of the inspection system to a flaw increases with its size, used as characteristic variable of the POD curve. In some cases, however, such behavior is not observed, which leads to a wrong, or at least biased, estimation of the POD. Moreover, in such cases, the choice of a parametric form of the POD curve a priori may not be an easy task. In recent years, quite a lot of solutions [3,4] have been proposed to carry out POD studies based on simulation tools [5]. Their use allows covering, with a low cost, a wider range of parameters variations. They can also provide a great help in studying complex cases, for which manufacturing of realistic mock-ups is difficult. This communication presents a simulation study of a particular eddy current testing inspection, presenting a non-monotonic signal response with respect to the characteristic value of interest. The generation of a large number of simulated inspection results enables us to calculate the POD curve without resorting to standard functional approaches. It provides also a way to generate confidently 2D POD maps, obtained when studying another parameter of interest together with the usual defect size.

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11:50 AM

Lamb Wave-Based Damage Quantification and Probability of Detection Modeling for Fatigue Life Assessment of Riveted Lap Joints

---**Jingjing He**, Dengjiang Wang, and Weifang Zhang, School of Reliability and System Engineering, Beihang University, Beijing, China

---This study presents an experimental and modeling study for damage detection and quantification in riveted lap joints. Embedded lead zirconate titanate piezoelectric (PZT) ceramic wafer-type sensors are employed to perform in-situ non-destructive testing during fatigue cyclical loading. A multi-feature integration method is developed to quantify the crack size using signal features of correlation coefficient, amplitude change, and phase change. In addition, probability of detection (POD) model is constructed to quantify the reliability of the developed sizing method. Using the developed crack size quantification method and the resulting POD curve, probabilistic fatigue life prediction can be performed to provide comprehensive information for decision-making. The effectiveness of the overall methodology is demonstrated and validated using several aircraft lap joint specimens from different manufactures and under different loading conditions.

Session 19

SESSION 19
NONLINEAR ULTRASONICS
Kathryn Matlack and Laurence J. Jacobs, Co-Chairpersons
Salmon-Snake

8:30 AM **Advancement of Time Reversal for Nonlinear Ultrasonic Inspection**
---**Timothy J. Ulrich**, Brian E. Anderson, Marcel C. Remillieux, Pierre-Yves E. Le Bas, and Colton Lake, Los Alamos National Laboratory, Geophysics, Los Alamos, NM 87545; Cedric Payan, Aix-Marseille University, IUT Département HSE LMA CNRS, Marseille, France; Michele Griffa, EMPA - Swiss Federal Laboratories for Materials Science and Technology, Concrete and Construction Chemistry Laboratory, Zurich, Switzerland; Parisa Shokouhi, BAM - Federal Institute for Materials Research and Testing, Non-Destructive Testing, Berlin, Germany

9:10 AM **Modeling the Nonlinear Hysteretic Response in DAET Experiments of Berea Sandstone: A Case-Study**
---**Claudio Pecorari**, ClampOn AS, Vaagsgaten 10 - NO-5160 Laksevaag, Bergen, Norway

9:30 AM **Detecting Localized Plastic Strain by a Scanning Collinear Wave Mixing Method**
---Guangxin Tang, Minghe Liu, and **Jianmin Qu**, Department of Mechanical Engineering, Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208; Laurence J. Jacobs, College of Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0360

9:50 AM **Nonlinear Ultrasonic Array Imaging of Fatigue Cracks**
---**Jack N. Potter**, Anthony J. Croxford, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

10:10 AM ***Break***

10:30 AM **Elastic Nonlinearity Parameters for Polycrystals**
---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska, Mechanical and Materials Engineering, NE 68588

10:50 AM **Nonlinear Guided Waves in Plates Undergoing Localized Micro-Structural Changes**
---**Vamshi Krishna Chillara** and Cliff J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

11:10 AM **Monitoring Microstructural Evolution in Steel Components with Nonlinear Ultrasound**
---**Kathryn H. Matlack**, Jin-Yeon Kim, and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; James J. Wall, Electric Power Research Institute, Charlotte, NC 28262; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

11:30 AM **Depth Profile Characterization with Noncollinear Beam Mixing**
---**Shaun L. Freed** and Jeong K. Na, Wyle, Aerospace Group, 2700 Indian Ripple Road, Dayton, OH 45440

11:50 AM ***Session Ends***

12:10 PM ***Lunch***

8:30 AM

Advancement of Time Reversal for Nonlinear Ultrasonic Inspection

---**Timothy J. Ulrich**, Brian E. Anderson, Marcel C. Remillieux, Pierre-Yves E. Le Bas, and Colton Lake, Los Alamos National Laboratory, Geophysics, Los Alamos, NM 87545; Cedric Payan, Aix-Marseille University, IUT Département HSE LMA CNRS, Marseille, France; Michele Griffa, EMPA - Swiss Federal Laboratories for Materials Science and Technology, Concrete and Construction Chemistry Laboratory, Zurich, Switzerland; Parisa Shokouhi, BAM - Federal Institute for Materials Research and Testing, Non-Destructive Testing, Berlin, Germany

---Time reversal, a method used to focus wave energy, has been employed over the past decade with nonlinear elastic wave spectroscopy for the purpose of materials characterization, defect localization and imaging. Early studies were performed entirely numerically with experimental studies in laboratory samples soon following. The robust and fast nature of the TR focusing together with the superior sensitivity of nonlinear ultrasonic techniques makes time reversal and nonlinear ultrasonic techniques viable candidates for the development of new inspection methods. Recent advances in signal processing, data analysis and laser vibrometry have resulted in technology developments approaching deployment for onsite inspection of civilian infrastructure, particularly nuclear power and waste storage facilities. This paper will present a brief history of this development and the latest advancements leading to the inspection of concrete and stainless steel materials in the context of nuclear fuel storage.

9:10 AM

Modeling the Nonlinear Hysteretic Response in DAET Experiments of Berea Sandstone: A Case-Study

---Claudio Pecorari, ClampOn AS, Vaagsgaten 10 - NO-5160 Laksevaag, Bergen, Norway

---Dynamic acousto-elasticity (DAE) allows probing the instantaneous state of a material while the latter slowly and periodically is changed by an external, dynamic source. In (D)AE investigations of geo-materials, hysteresis of the material's modulus defect displays intriguing features which have not yet been interpreted in terms of any specific mechanism occurring at atomic or mesoscale. Here, experimental results on dry Berea sandstone, which is the rock type best investigated by means of DAET, are analyzed in terms of three rheological models providing simplified representations of mechanisms involving dislocations interacting with point defects distributed along the dislocations' core or glide plane, and microcracks with finite stiffness in compression. Constitutive relations linking macroscopic strain and stress are derived. From the latter, the modulus defect associated to each mechanism is recovered. These models are employed to construct a composite one which is capable of reproducing several of the main features observed in the experimental data. The limitations of the present approach and, possibly, of the current implementation of DAE are discussed.

9:30 AM

Detecting Localized Plastic Strain by a Scanning Collinear Wave Mixing Method
---Guangxin Tang, Minghe Liu, and **Jianmin Qu**, Department of Mechanical Engineering, Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208; Laurence J. Jacobs, College of Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0360

---When the frequencies of a pair of collinear shear and longitudinal waves satisfy the resonant condition, mixing of these two primary waves generates a third, resonant shear wave that propagates in the direction opposite to the propagating direction of the primary shear wave. In this study, experiments were conducted to demonstrate that the acoustic nonlinearity parameter at the location of the mixing zone can be obtained by measuring the resonant shear wave. Since the location of the mixing zone can be controlled by adjusting the trigger time of the transducers that generate the primary waves, this collinear wave mixing technique enables the scanning of a bar sample to measure the distribution of acoustic nonlinearity along the bar. To demonstrate this scanning capability, bar samples with non-uniform acoustic nonlinearity parameters were fabricated by inducing localized plastic deformation at known locations. Scanning collinear wave mixing tests conducted on such bar samples clearly identified the locations of the plastic zone. These results show that collinear wave mixing is a promising method for scanning the test sample to map out the distribution of localized plastic deformation.

9:50 AM

Nonlinear Ultrasonic Array Imaging of Fatigue Cracks
---Jack N. Potter, Anthony J. Croxford, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---A technique is presented for the imaging of acoustic nonlinearity which requires just a single ultrasonic array. Acoustic nonlinearity is measured by evaluating the difference in energy of the transmission bandwidth within the diffuse field produced through sequential and parallel focusing. The technique is demonstrated experimentally by imaging high cycle fatigue cracks and is shown to provide both higher contrast and more precise defect sizing than linear array imaging. Furthermore, the separation of linear and nonlinear imaging modalities is demonstrated.

10:30 AM

Elastic Nonlinearity Parameters for Polycrystals
---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska, Mechanical and Materials Engineering, NE 68588

---Absolute measurement of the nonlinearity parameter requires intimate knowledge of the inherent elastic nonlinearities that may be present in the sample along with additive contributions prior to the first measurement. The elastic contribution is defined through the nonlinear wave equation and consists of combinations of second- and third-order elastic constants. The absolute nonlinearity parameter for high purity single crystals is well approximated through its single-crystal elastic constants. Researchers often assume that the elastic properties are isotropic when dealing with polycrystalline metals. This presentation will focus on nonlinear parameter definitions of the polycrystal that are based on anisotropic single crystals. First, the nonlinearity parameter will be defined for polycrystals using Voigt, Reuss, Hill, and self-consistent averaging techniques for a variety of different single-crystal symmetries. An extension of the technique to alloyed metals with varying concentrations of constituents is also given. A comparison between theoretical and experimental nonlinearity parameters taken from Cu-\%Al and Ni samples is made. It is shown that considerable error exists when the polycrystal is assumed to consist of isotropic grains. Thus, the grain anisotropy plays a critical role in the overall nonlinear response of the polycrystal. Lastly, theoretical expressions for the nonlinearity parameter are derived in terms of spherical harmonics in order to account for macroscopic grain texture. The sensitivity to the grain texture may lead to the development of new nonlinear techniques for nondestructive texture analysis.

10:50 AM

Nonlinear Guided Waves in Plates Undergoing Localized Micro-Structural Changes

---**Vamshi Krishna Chillara** and Cliff J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Nonlinear guided waves have been successfully employed to monitor micro-structural changes in plate-like structures. The beta parameter estimated from the cumulative harmonic generation is used as a measure of nonlinear behavior associated with micro-scale damage. Earlier studies investigated the effect of global nonlinearity, namely the effect of nonlinearity is considered to be present throughout the wave propagation path. Also, the severity of damage has been modeled as a change in higher order elastic constants. However, a quite distinct approach to model micro-scale damage can be adopted wherein, the effect of nonlinearity is assumed to be localized and the severity of damage is assumed to be proportional to the spatial extent to which the damage has progressed. This work aims to study the above aspects of modeling micro-scale damage from a numerical standpoint with the intent of connecting nonlinear ultrasonics with aspects of the material microstructure. Numerical simulations are carried out to study the effect of localized nonlinearities on wave propagation using COMSOL, a commercial finite element package. Some important aspects of nonlinear guided wave propagation in the current setting are discussed. In particular, the cumulative nature of harmonics in a plate with periodic, localized nonlinearities is discussed.---This material is based upon work supported by the Nuclear Energy Universities Program under Award number 00102946 and the National Science Foundation under Award number 1300562.

11:10 AM

Monitoring Microstructural Evolution in Steel Components with Nonlinear Ultrasound

---**Kathryn H. Matlack**, Jin-Yeon Kim, and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; James J. Wall, Electric Power Research Institute, Charlotte, NC 28262; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

---Material damage in structural components is driven by microstructural evolution that occurs at low length scales and begins early in component life. In metallic materials, these microstructural features are known to cause measurable changes in the acoustic nonlinearity parameter. Physically, the interaction of a monochromatic ultrasonic wave with microstructural features such as dislocations, precipitates, and vacancies, generates a second harmonic wave that is proportional to the acoustic nonlinearity parameter. These nonlinear ultrasonic techniques thus have the capability to evaluate initial material damage, particularly before crack initiation and propagation occur. This talk will discuss how the nonlinear ultrasonic technique of second harmonic generation can be used as a nondestructive evaluation tool to monitor microstructural changes in steel, with a focus on characterizing neutron radiation- and thermally-induced embrittlement in nuclear reactor steels and model components. Experimental evidence and analytical models linking microstructural evolution with changes in the acoustic nonlinearity parameter will be presented.

11:30 AM

Depth Profile Characterization with Noncollinear Beam Mixing
---**Shaun L. Freed** and Jeong K. Na, Wyle, Aerospace Group, 2700 Indian Ripple Road, Dayton, OH 45440

---Noncollinear beam mixing is an ultrasonic approach to quantify elastic nonlinearity within a subsurface volume of material. The technique requires interaction between two beams of specific frequency, angle, and vibration mode to generate a third beam propagating from the intersection volume. The subsurface depth to interaction zone is adjusted by changing the separation distance between the two input transducers at the surface, and the amplitude of the third generated beam is proportional to the elastic nonlinearity within this interaction zone. Therefore, depth profiling is possible if a suitable parameter is established to normalize the detected signal independent of propagation distances and input amplitudes. This foundational effort has been conducted toward developing such a parameter for depth profile measurements in homogeneous aluminum that includes corrective terms for attenuation, beam overlap noise, beam spread, and input amplitudes. Experimental and analytical results are provided, and suggested applications are discussed toward characterizing property graded and layered materials as well as microstructure characterization feasibility.
---This work was supported by Wyle IRAD funding.

Session 20

Wednesday, July 23, 2014

SESSION 20

GUIDED WAVES III

Peter Cawley and Ronald A. Roberts, Co-Chairpersons

Peregrines

1:30 PM **Adhesive Defect Detection in Composite Adhesive Joints Using Phased Array Transducers**
---**Baiyang Ren** and Cliff J. Lissenden, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

1:50 PM **Coherent, Data-Driven Lamb Wave Localization Under Environmental Variations**
---**Joel B. Harley**, David W. Greve, and José M.F. Moura, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213; Chang Liu and Irving J. Oppenheim, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213

2:10 PM **Guided Wave Propagation in Anisotropic Materials and the Practical Implications for Operating Point Selection**
---**Anthony J. Croxford** and Osvaldas Putkis, University of Bristol, Department of Mechanical Engineering, Bristol, Avon, United Kingdom; Roger P. Dalton, Qinetiq Ltd., Farnborough, United Kingdom

2:30 PM **Excitability of Guided Waves in Composites with PWAS Transducers**
---**Yanfeng Shen** and Victor Giurgiutiu, Department of Mechanical Engineering, University of South Carolina, 300 Main Street, A237, Columbia, SC 29208

2:50 PM **Designing of Sparse 2D Arrays for Lamb Wave Imaging Using Co-Array Concept**
---**Lukasz Ambrozinski**, T. Stepinski, and T. Uhl, AGH University of Science and Technology, Department of Robotics and Mechatronics, Krakow, Poland

3:10 PM ***Break***

3:30 PM **Axial Guided Wave Technique for Rapid Inspection of the “Noodle” Regions in a Stiffened Composite Component**
---**Prabhakaran Manogaran**, Prabhu Rajagopal, and Krishnan Balasubramaniam, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, 600036, Tamil Nadu, India

3:50 PM **Experimental Study of A_0 Lamb Wave Tomography on Pipes**
---**Matthias Seher**, Peter Huthwaite, Michael J. S. Lowe, and Peter Cawley, Imperial College, Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

4:10 PM **Investigating the Effects of Temperature Variation for Improving the Extensibility of Data-Driven Damage Diagnosis Methods Using Ultrasonic Guided-Waves in Pipes**
---**Matineh Eybpoosh**, Mario Berges, and Hae Y. Noh, Carnegie Mellon University, Civil and Environmental Engineering, Pittsburgh, PA 15217

4:30 PM **The Green’s Function for Guided Waves in a Three-Dimensional Elastic Plate**
---**Heung Son Lee** and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Republic of Korea

4:50 PM **Development of the Electromagnetic Technology for Broken Rail Detection from a Mobil Platform**
---**Yuri Plotnikov** and Tannous Frangieh, GE Global Research, Niskayuna, NY 12309; Arun Raghunathan and Samhitha Palanganda, GE Global Research, Bangalore, India; Ajith K. Kumar and Steven Ehret, GE Transportation, Erie, PA 16531; Joseph Noffsinger and Jeffrey Fries, GE Transportation, Kansas City, MO 64153

1:30 PM

Adhesive Defect Detection in Composite Adhesive Joints Using Phased Array Transducers

---**Baiyang Ren** and Cliff J. Lissenden, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

---Composite materials are widely used in aircraft structures due to their high specific stiffness and strength. The laminated nature of composite structures makes them subject to disbond and delamination. These types of defects will compromise the integrity of the structure and need to be monitored. To monitor aircraft structures, light weight transducers capable of large area coverage are beneficial. Ultrasonic guided waves are able to travel long distance and are sensitive to localized defects. The multi-modal characteristic of propagating guided waves requires optimal mode selection and excitation. Phased array transducers provide good versatility for optimal mode excitation since they can excite different guided wave modes preferentially. Phased array transducers designed for SHM applications are employed in this work to study the interaction between adhesive defects and guided wave modes. Amplitude ratios and wave packet composition are utilized as defect indicators that are uniquely available due to the phased array transducers.

1:50 PM

Coherent, Data-Driven Lamb Wave Localization under Environmental Variations
---**Joel B. Harley**, David W. Greve, and José M.F. Moura, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213; Chang Liu and Irving J. Oppenheim, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213

---To develop new, reliable guided wave structural monitoring (SHM) systems, there is significant interest in developing methods that (1) better leverage the complex, multimodal, and dispersive behavior of guided waves modes and (2) are resilient to external environmental and operational variations that alter wave propagation. By achieving the first goal, we can utilize more information to develop new SHM systems that operate with greater precision across much larger areas. By achieving the second goal, we can build new SHM systems that can operate for longer periods over of time in much harsher environments. In prior work, we developed a method known as data-driven matched field processing [Harley and Moura 2014] to recover the complex, dispersive characteristics of Lamb waves and use this information to coherently localize damage. We showed this method to exhibit significantly better localization accuracy and resolution than conventional, incoherent methods. In prior work, we also developed methods based on the scale transform [Harley and Moura 2012] and singular value decomposition [Liu et. al 2014] to reduce signal distortion due to temperature. We demonstrated these methods to be computational fast and resilient compared with other approaches. In this paper, we integrate data-driven matched field processing with scale transform and singular value decomposition temperature compensation approaches to produce a robust, high resolution Lamb wave localization method. We experimentally demonstrate this integrated approach by localizing a 5 cm diameter cylindrical mass on an aluminum plate with spatially non-uniform temperature variations. We compare the performance of each temperature compensation method and show singular value decomposition to exhibit the best overall results. We also discuss the challenges with integrating temperature compensation and coherent localization methods, such as data-driven matched field processing.---The work of Joel B. Harley was partially supported by a National Science Foundation Graduate Research Fellowship under Grant No. 0946825.

2:10 PM

Guided Wave Propagation in Anisotropic Materials and the Practical Implications for Operating Point Selection

---Anthony J. Croxford and Osvaldas Putkis, University of Bristol, Department of Mechanical Engineering, Bristol, Avon, United Kingdom; Roger P. Dalton, Qinetiq Ltd., Farnborough, United Kingdom

---Ultrasonic guided wave propagation in anisotropic attenuative materials like CFRP is much more complicated than in isotropic materials. Propagation phenomena need to be understood and quantified before reliable NDE/SHM inspections systems can be realized. The propagation characteristics: energy velocity, dispersion, mode coupling, energy focusing factor and attenuation are considered in this paper. Concepts of minimum resolvable distance and sensitivity maps are extended to anisotropic attenuative materials in order to provide the means for comparison of different guided wave modes in composite materials. It is shown that minimum resolvable distance is a more complex phenomena in anisotropic materials and care must be taken when considering the directions of propagation ultimately detection capability. Similarly when designing an inspection the distribution of energy in a structure must be considered to determine the feasibility of a given inspection. This paper presents a framework for selecting the optimum operating point for possible NDE/SHM applications on composite materials. Fundamental guided waves in the low frequency regime for highly anisotropic CFRP plates are investigated experimentally and theoretically and their practical implications discussed.

2:30 PM

Excitability of Guided Waves in Composites with PWAS Transducers
---**Yanfeng Shen** and Victor Giurgiutiu, Department of Mechanical Engineering, University of South Carolina, 300 Main Street, A237, Columbia, SC 29208

---Piezoelectric Wafer Active Sensors (PWAS) are convenient enablers for generating and receiving ultrasonic guided waves. The wide application of composite structures has put new challenges for the Structural Health Monitoring (SHM) and Nondestructive Evaluation (NDE) community due to the general anisotropic behaviors and complicated guided wave features in composites. The excitability of guided waves in composite structures directly influences the implementation of active sensing systems to achieve the best interrogation of certain sensing directions. This paper presents a hybrid modeling technique for studying the excitably of guided waves in composite structures with PWAS transducers. This hybrid technique comprehensively covers local finite element model (FEM), semi-analytical finite element (SAFE) method, and analytical guided wave solutions. Harmonic analysis of a small-size local FEM with non-reflective boundaries (NRB) was carried out for obtaining guided wave generation features in plate structures. The PWAS transducers were modeled with coupled filed elements. Thus, the FEM can fully capture the geometry and material property effects of PWAS transducers and their influence on the guided wave excitation. SAFE method was used to obtain the complicated guided wave features in composites such as dispersion curves and mode shapes. The SAFE procedure was coded into MATLAB Graphical User Interface (GUI), and the software SAFE-DISPERSION was developed. To study the excitability of each wave mode, we considered all the possible wave modes being generated simultaneously and propagating independently. The analytical wave expressions based on the exact guided wave solution with Hankel functions were used to join the SAFE method and the local FEM. Formulated in frequency domain, the hybrid model is highly efficient, providing an over determined equation system for the calculation of mode participation factors. Case studies and experiments were carried out: (1) the Lamb wave excitability in an aluminum plate was investigated and compared with classical pin force models to show the feasibility of the hybrid technique; (2) the guided wave excitability in a woven glass fiber composite (GFRP) plate was studied and compared with experiments. The paper finishes with summary, conclusions, and suggestions for future work.

2:50 PM

Designing of Sparse 2D Arrays for Lamb Wave Imaging Using Co-Array Concept
---**Lukasz Ambrozinski**, T. Stepinski, and T. Uhl, AGH University of Science and Technology, Department of Robotics and Mechatronics, Krakow, Poland

---2D ultrasonic arrays have a considerable application potential in Lamb wave based SHM systems, since they enable equivocal damage imaging and in even some cases wave-mode selection. Recently, it has been shown that the 2D arrays can be used in SHM applications in a synthetic focusing (SF) mode, which is much more effective than the classical phase array mode commonly used in NDT. The SF mode assumes a single element excitation of subsequent transmitters and off-line processing the acquired data. In the simplest implementation of the technique, a single multiplexed input and output channels are required, which results in significant hardware simplification. Application of the SF mode for 2D arrays creates additional degrees of freedom during the design of the array topology, which complicates the array design process, however, it enables sparse array designs with performance similar to that of the fully populated dense arrays. In this paper we present the co-array concept to facilitate synthesis process of an array's aperture used in the multistatic synthetic focusing approach in Lamb waves-based imaging systems. In the coherent imaging, performed in the transmit/receive mode, the sum co-array is a morphological convolution of the transmit/receive sub-arrays. It can be calculated as the set of sums of the individual sub-arrays' elements locations. The co-array framework will be presented here using a few different arrays topologies; starting from cross-like arrays a number of 2D configurations will be considered, e.g. square and star-shaped arrays. The approach will be discussed in terms of point spread-functions and beam patterns of the resulting imaging systems. Both simulated and experimental results will be included.---Presented work was financed within the research grant no. 2011/01/B/ST8/07210 “Theoretical basis for structural health monitoring by means of inverse problem solution under uncertainty” financed by the National Science Centre of Poland.

3:30 PM

Axial Guided Wave Technique for Rapid Inspection of the “Noodle” Regions in a Stiffened Composite Component

---**Prabhakaran Manogaran**, Prabhu Rajagopal, and Krishnan Balasubramaniam, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, 600036, Tamil Nadu, India

---Composite structures are used in a wide variety of applications. The use of stiffened composites is common in aerospace box-like components and provides the additional stiffness required. Examples of such stiffened structural geometries include airfoils, fuselage, wing box, tail section, etc. The inspection of the radius filler “noodle” that fills the interface between skin and stiffener has been of great concern to the aerospace composites industry. This paper describes the 3D FEM models of the ultrasonic axially propagating guided wave modes. Additionally, the models were used for understanding their confinement in the noodle region, their leakage to the remaining sections of the component and their interaction with defects of different types, sizes and their locations along noodle region. The ultrasonic guided wave modes that propagate along the length of the noodle were identified using the 3D finite element model and dispersion curves are calculated using the semi-analytical finite element (SAFE) technique. These simulations were validated using graphite-epoxy test coupons and components from aerospace industry.

3:50 PM

Experimental Study of A_0 Lamb Wave Tomography on Pipes
---**Matthias Seher**, Peter Huthwaite, Michael J. S. Lowe, and Peter Cawley, Imperial College, Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---Corrosion damage in inaccessible regions presents a significant challenge to the petrochemical industry, and determining the remaining thickness is important to establish the remaining service life. Guided wave tomography is one solution and involves transmitting Lamb waves through the area of interest to reconstruct the remaining wall thickness based on the received signals. This avoids the need to access all points on the surface, making the technique well suited to inspection beneath supports. Guided wave tomography has been widely demonstrated for idealized cases, but there are many practical scenarios where external factors could influence the thickness reconstruction, and it is important that the effects of these are understood and quantified. This talk focuses on pipe supports, and will attempt to quantify the effects that different supports have on the thickness reconstructions for a representative defect, using an experimental setup. This talk will also demonstrate the use of an array of electromagnetic acoustic transducers (EMATs), developed to excite pure A_0 Lamb waves. These were used for transduction since coupled piezoelectric transducers have been found to scatter the guided waves.

4:10 PM

Investigating the Effects of Temperature Variation for Improving the Extensibility of Data-Driven Damage Diagnosis Methods Using Ultrasonic Guided-Waves in Pipes

---**Matineh Eybpoosh**, Mario Berges, and Hae Y. Noh, Carnegie Mellon University, Civil and Environmental Engineering, Pittsburgh, PA 15217

---The effects of variation in environmental and operational conditions (EOCs) (e.g., temperature, stress/loading, coupling material, etc.) on guided-waves range from generation of additional wave modes to changes in the wave velocity, attenuation rate, signal shape, etc. Such effects degrade the performance of damage detection, by masking the changes caused by structural anomalies and introducing type I and II errors. EOC effects have been widely studied for individual wave modes, and mostly for simple structures like plates. However, guided-waves obtained from structures like pipes operating under varying EOCs, are the results of complex superposition of a number of modes, with different sensitivities to EOC variations. Moreover, the link between the investigated EOC effects on guided-waves and damage diagnosis approaches is not well-studied. In other words, the way the identified damage-sensitive features (DSFs) and damage detection methods will work under different EOC scenarios is not known. This limits the real-world applicability of the current NDE approaches, since it is not known how they can be extended to different EOC scenarios that may occur during the operation of pipes. This paper summarizes experimental results for studying the effects of temperature variations on damage diagnosis of pipes using ultrasonic guided-waves. First, we describe a laboratory setup designed to control the temperature variation in an Aluminum pipe. Pitch-catch ultrasonic guided-waves are recorded under temperatures varying from 24 ℃ up to 44 ℃ with 0.5℃ increments. Effects of temperature are also simulated and dispersion curves corresponding to this temperature range are obtained to provide theoretical ground truth for better understanding of experimental observations, and for estimation of physical parameters of wave propagation such as wave velocities, dispersion behaviors, etc. Next, we investigate the performance of current temperature characterization methods, namely baseline stretching/compressing methods, for different ranges of temperature. We show how such methods fail to characterize larger temperature differences, mainly due to shape distortion caused by different sensitivity of propagating modes. The ineffectiveness of these methods for smaller temperature differences is also discussed through (1) illustrating how the effects of damage (e.g., amplitude change) are masked by leftover noises from baseline subtraction, (2) showing the way such methods manipulate the information carried by signals (e.g., frequency content). Finally, we report the result of case studies that motivate quantitative modeling of the effects of temperature on DSFs and damage detection methods, rather than guided-waves time traces. These results reveal that transforming to feature domain does not resolve the EOC challenges completely. For example, we show how the sensitivity of DSFs (e.g., principal components) to damage varies under different ranges of temperature variations. At the end, we provide suggestions for quantifying the observed behaviors for compensating the unwanted effects of temperature on the studied DSFs.

4:30 PM

The Green's Function for Guided Waves in a Three-Dimensional Elastic Plate
---**Heung Son Lee** and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Republic of Korea

---In this work, we newly derive the time-harmonic dyadic Green's functions for a three-dimensional elastic plate, the form of which is quite different from forms derived earlier. Our form appears to be more advantageous in solving complicated scattering problems. Unlike earlier works, our derivation is based on the Ohm-Rayleigh method, a method commonly used in electromagnetic wave problems, not commonly employed in elastodynamic problems. In the present approach, the eigenfunctions of a traction-free plate on its top- and bottom-surfaces are selected to be the kernel functions of an integral transform. After deriving the orthogonality relation among the eigenfunctions in their thickness direction, the Green's functions are expressed in an integral form involving eigenfunctions. After the integral expressions are evaluated by using the residue theorem, the desired the dyadic Green's functions are finally obtained. The results are given both in the Cartesian and cylindrica l coordinates. As applications, scattering by a cavity or inclusion and radiation by a surface traction are solved by the T-matrix method using the Green's function.---This research was supported by the National Research Foundation of Korea (NRF) grant (No. 2013-035194) funded by the Korean Ministry of Education, Science and Technology (MEST) contracted through IAMD at Seoul National University and the Brain Korea 21 Plus Project in 2014.

4:50 PM

Development of the Electromagnetic Technology for Broken Rail Detection from a Mobil Platform

---**Yuri Plotnikov** and Tannous Frangieh, GE Global Research, Niskayuna, NY 12309; Arun Raghunathan and Samhitha Palanganda, GE Global Research, Bangalore, India; Ajith K. Kumar and Steven Ehret, GE Transportation, Erie, PA 16531; Joseph Noffsinger and Jeffrey Fries, GE Transportation, Kansas City, MO 64153

---Timely detection of breaks in running rails remains a topic of significant importance for the railroad industry. GE has been investigating new ideas of the Rail Integrity Alert System or RIAS technology that can be implemented on a wide range of the rolling stock platforms including locomotives, passenger and freight cars. The focus of the project is to establish a simple, non-contact, and inexpensive means of nondestructive inspection by fusion of known solutions with new technology development that can result in detection with high reliability. A scaled down model of a typical locomotive-track system has been developed at GE Global research for detailed study of the detection process. In addition, a finite element model has been established and used to understand distribution of the magnetic field and currents in such a system. Both models have been using the rails and wheel-axles geometry to establish a realistic model that would provide the electric current and magnetic field distribution close to the real world phenomenon. Initial magnetic field maps were obtained by scanning 1:15 model constructed of steel bars using a 3D scanner and an inductive coil. Sensitivity to a broken rail located between two locomotive axles simulated by an opening in this metallic frame was demonstrated. Further investigation and optimization was conducted on a larger, 1:3 scale, physical model and by running mathematical simulations. Special attention was paid to consistency between the finite element and physical model results. The obtained results allowed establishment of a working frequency range, inductive current injection into the rail-wheel-axle loop and measuring the electromagnetic response to a broken rail. The verification and full scale system prototype tests are following the laboratory experiments and mathematical simulations.

Session 21

SESSION 21
COMPOSITES I
Mahmood Haq and Gerges Dib, Co-Chairpersons
Pines-Willows

1:30 PM **Simulation of Ultrasonic Inspection of Curved Composites Using a Hybrid Semi-Analytical/Numerical Code**
---Steve Mahaut, CEA-LIST, Digiteo Labs, Bat565, CEA Saclay 91191 Gif-sur-Yvette, France; **Frédéric Reverdy**, CEA-LIST, 18 rue Marius Terce, 31025 Toulouse, France; Nicolas Dominguez, Airbus Group Innovations, 18 rue Marius Terce, 31025 Toulouse, France; Philippe Dubois, EXTENDE, 15 Avenue Emile Baudot, 91 300 Massy, France

1:50 PM **Ultrasonic Defect Evaluation Using DGS-Diagrams Modified for the Inspection of Anisotropic Composite Materials**
---**Martin Spies**, Alexander Dillhöfer, and Hans Rieder, Fraunhofer Institute for Industrial Mathematics ITWM, Ultrasonic Imaging Group, 67663 Kaiserslautern, Germany

2:10 PM **Guided Waves for the Detection and Classification of Impact Damage in Composites**
---Bibi I. S. Murat, Pouyan Khalili, and **Paul Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

2:30 PM **Feasibility of PZT Ceramics for Impact Damage Detection in Composite Structures**
---**Gerges Dib**, Oleksii Karpenko, Lalita Udpa, and Satish S. Udpa, Nondestructive Evaluation Laboratory, Michigan State University, East Lansing, MI 48824; Ermias Koricho, Anton Khomenko, and Mahmoodul Haq, Composite Vehicle Research Center, Michigan State University, East Lansing, MI 48910

2:50 PM **Impact Location Estimation in Anisotropic Structures**
---**Jingru Zhou** and V. John Mathews, University of Utah, Department of Electrical and Computer Engineering, Salt Lake City UT 84112

3:10 PM ***Break***

3:30 PM **Progress on Automated Data Analysis Algorithms for Ultrasonic Inspection of Composites**
---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; David S. Forsyth, TRI/Austin, Austin, TX 78733-6201; John T. Welter, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433

3:50 PM **Structural Health Monitoring of Adhesively Bonded Lap-Joints During Fatigue Testing**
---**Oleksii Karpenko**, Gerges Dib, Lalita Udpa, and Satish Udpa, Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48864; Ermias Koricho, Anton Khomenko, and Mahmoodul Haq, Composite Vehicle Research Center, Lansing, MI 48910

4:10 PM **Parametric Study Using Modal Analysis of a Bi-Material Plate with Defects**
---**Shane A. Esola** and Antonios Kontsos, Drexel University, Theoretical & Applied Mechanics Group, Department of Mechanical Engineering & Mechanics, Philadelphia, PA 19104; Ivan Bartoli, Drexel University, Department of Civil, Architectural, & Environmental Engineering, Philadelphia, PA; Suzanne E. Horner and James Q. Zheng, U.S. Army, Program Executive Office – Soldier, Fort Belvoir, VA 22060

4:30 PM **Meso-Scale Imaging of Composite Materials**
---**Robert Grandin**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

1:30 PM

Simulation of Ultrasonic Inspection of Curved Composites Using a Hybrid Semi-Analytical/Numerical Code

---Steve Mahaut, CEA-LIST, Digiteo Labs, Bat565, CEA Saclay 91191 Gif-sur-Yvette, France; **Frédéric Reverdy**, CEA-LIST, 18 rue Marius Terce, 31025 Toulouse, France; Nicolas Dominguez, Airbus Group Innovations, 18 rue Marius Terce, 31025 Toulouse, France; Philippe Dubois, EXTENDE, 15 Avenue Emile Baudot, 91 300 Massy, France

---Carbon Fiber reinforced composites are increasingly used in structural parts in the aeronautics industry, as they allow to reduce the weight of aircrafts while maintaining high mechanical performances. However, such structures can be complicated to inspect due to their complex geometries and complex composite properties, leading to highly heterogeneous and anisotropic materials. Different potential damages and manufacturing flaws related to these parts are to be detected: porosities, ply waviness, delaminations after impact… Ultrasonic inspection, which is commonly used to test the full volume of composite panels, thus has to cope with both complex wave propagation (within anisotropic parts whose crystallographic orientation varying according to the layers structure) and flaw interaction (local distortion of plies such as ply waviness, small pores, structural noise due to periodicity patterns…). Developing NDT procedures for those parts therefore requires simulation tools to help for understanding those phenomena, and to optimize probes and techniques. Within the CIVA multi-techniques platform, CEA-LIST has developed semi-analytical tools for ultrasonic techniques, which have the advantages of high computational efficiency (fast calculations), but with limited range of application due to some hypothesis (for instance, homogenization approaches which don't allow to take account of structural noise). On the other hand, numerical methods such as finite element (FEM) or finite difference in time domain (FDTD) are more suitable to compute ultrasonic wave propagation and defect scattering in complex materials such as composite but require more computational efforts. Hybrid methods couple semi-analytical solutions and numerical computations in limited spatial domains to handle complex cases with high computation performances. In CIVA we have integrated a hybrid model that combines the semi-analytical methods developed at CEA to FDTD modelling developed at Airbus Group Innovations. In this paper we give some examples of the hybrid method for the inspection of complex composite parts, with various flaws. Examples are related to curved composite parts with varying anisotropy (layers follow the curvature of the component), ply waviness of different widths and heights, calibration flaws, and effects of the inter-ply epoxy layer to structural noise. Applications and discussions of inspection using single or phased array probes are also given.---The research leading to these results has received funding from the European Community's Seventh Framework Program (FP7/2007-2013) under Grant Agreement No. 285549: SIMPOSIUM project.

1:50 PM

Ultrasonic Defect Evaluation Using DGS-Diagrams Modified for the Inspection of Anisotropic Composite Materials
---**Martin Spies**, Alexander Dillhöfer, and Hans Rieder, Fraunhofer Institute for Industrial Mathematics ITWM, Ultrasonic Imaging Group, 67663 Kaiserslautern, Germany

---Lightweight components fabricated from composite materials gain increasing importance, but also raise considerable challenges for ultrasonic inspection due to the generally anisotropic material properties. Simulations help in understanding the partially complex wave propagation phenomena, but many models require elaborate computation techniques. Also, for practical applications it is desirable to be able to exploit analogies to the inspection of conventional materials. In this contribution, we consider the calculation of DGS (distance-gain-size)-diagrams for composite materials. We exploit formulations of the far-field directivities for transducers with circular or rectangular apertures, which are totally analogous to the well-known expressions for isotropic materials, but account for the anisotropic material properties. We explain the basic considerations and show representative results for DGS-diagrams for commercially available transducers. We illustrate the modified procedure for a unidirectionally carbon-fiber reinforced composite material and discuss differences to the ultrasonic inspection of conventional materials.

2:10 PM

Guided Waves for the Detection and Classification of Impact Damage in Composites

---Bibi I. S. Murat, Pouyan Khalili, and **Paul Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

---Carbon fiber laminate composites, consisting of layers of polymer matrix reinforced with high strength carbon fibers, are widely employed for aerospace structures. For aerospace applications they offer a number of advantages including a good strength to weight ratio. However, impact during the operation and servicing of the aircraft can lead to barely visible and difficult to detect damage. Depending on the severity of the impact, fiber and matrix breakage or delaminations can occur, reducing the load carrying capacity of the structure. Efficient nondestructive testing of composite panels can be achieved using guided ultrasonic waves propagating along the structure. Impact damage was induced in the composite panels using standard drop weight procedures. The guided wave scattering at the impact damage was measured using a noncontact laser interferometer, quantified, and compared to baseline measurements on undamaged composite panels. Significant scattering of the A0 guided wave mode was observed, allowing for the detection of barely visible impact damage. The impact damage was further characterized using standard ultrasonic C-scans. The guided wave scattering was modelled using full three-dimensional Finite Element (FE) simulations, and the influence of the different damage mechanisms investigated from a parameter study. Good agreement between experiments and predictions was found. The sensitivity of guided waves for the detection of barely visible impact damage in composite panels has been verified.

2:30 PM

Feasibility of PZT Ceramics for Impact Damage Detection in Composite Structures

---**Gerges Dib**, Oleksii Karpenko, Lalita Udpa, and Satish S. Udpa, Nondestructive Evaluation Laboratory, Michigan State University, East Lansing, MI 48824; Ermias Koricho, Anton Khomenko, and Mahmoodul Haq, Composite Vehicle Research Center, Michigan State University, East Lansing, MI 48910

---Fiber reinforced plastic composites are becoming widely used in vehicles and airframe structures due to their high strength to weight ratio. However unlike metals, the multilayered composite structure are more susceptible to damage mechanisms such as disbonds and delaminations due to impacts. It is often difficult to visually detect the damage. Lead-Zirconate-Titanate (PZT) thin films are becoming popular for in-situ structural health monitoring due to their small size, high piezoelectric coupling coefficient, and ease of surface-mounting and/or embedding in composite structures. A network of such transducers could be utilized for damage detection using guided wave techniques, impedance techniques, or passive impact detection techniques. However, the PZT films are subject to the same impact probabilities that the structure encounters. If the transducers fail due to the subjected impacts, they can result in false readings and ultimately failing to correctly detect damage in the structure. This paper presents a feasibility study using model-based simulation of ultrasonic guided wave inspection using PZT sensors surface mounted and embedded in GFRP composite structures. The effects of failed PZT sensors on damage detection are investigated. Experimental validation of simulation results will be presented.

2:50 PM

Impact Location Estimation in Anisotropic Structures

---**Jingru Zhou** and V. John Mathews, University of Utah, Department of Electrical and Computer Engineering, Salt Lake City UT 84112

---Impacts that occur during service or maintenance are major causes of in-service damage of aerospace structures. Therefore, impact location estimation techniques are useful for structural health monitoring (SHM), especially for large and expensive structures such as aircraft and space vehicles. In this paper, we consider composite structures that are anisotropic and consequently have more complex wave propagation properties than isotropic structures. The SHM system employs a passive sensor array that acquires and processes signals emitted from impact locations. Unlike many published solutions to this problem [1], the algorithm of this paper does not require the waveform velocity profile for the structure. The method employs time-of-arrival information and estimates the impact location and the average velocity of one or more modes of propagation between the impact location and each sensor on the structure jointly. Making use of the geometric relationships between the vertices of the triangles formed by the impact location and any two sensors on the structure, the method models the impact location and velocity estimation tasks as a nonlinear optimization problem with multiple quadratic constraints and solves the problem using first order optimality conditions [2]. This paper also derives a computational simplification for the calculation of the exact solution to the location and velocity estimation problem, making the approach capable of real-time implementation. Numerical simulations as well as experimental results using a carbon/epoxy composite panel demonstrating accurate location estimation results are included in the paper. Results demonstrating the robustness of the method to environmental variations (for example, temperature changes) in the experimental conditions are also included. The algorithm of this paper is able to perform fast and accurate impact location estimation without the need to carefully calibrate the structure for wave propagation characteristics and environmental factors. Consequently, this method has the potential to become a key component in structural health monitoring systems for complex, composite structures typical in aerospace applications.---This work is supported in part by the National Aeronautics and Space Administration (Award No. NNM13AA12G) and the Air Force Office of Scientific Research (Award No. FA95501210291).

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3:30 PM

Progress on Automated Data Analysis Algorithms for Ultrasonic Inspection of Composites

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; David S. Forsyth, TRI/Austin, Austin, TX 78733-6201; John T. Welter, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433

--The ultrasonic inspection of large composite structures requires significant manpower and production time. To address this burden and ideally increase inspection reliability, progress is presented on the development of ADA software to make calls on indications satisfying the call criteria while minimizing false calls. The data analysis task follows standard procedures for analyzing signals for time-of-flight indications and backwall amplitude dropout. Adaptive gates have been implemented to compensate for ply drop and panel curvature variation. Once part boundaries and transitions are identified, feature extraction algorithms are applied to through-thickness and backwall C-scan images based on amplitude and size criteria. New algorithms have been implemented to reliably identify indications in time-of-flight images near the front and back walls of composite panels. Adaptive call criteria have also been applied to address sensitivity to variation in backwall signal level, panel thickness variation, and internal signal noise. ADA processing results are presented for a variety of test specimens that include inserted materials and discontinuities produced under poor manufacturing conditions. Parametric studies were performed to evaluate detection and false call results with respect to varying algorithm settings. To address some gaps in the test data set, simulated porosity data sets were created to further challenge the classification algorithms. Recent work has also been performed to address improving detection performance and reduce false calls for bonded regions. Automated reporting features have been implemented to provide support to the operator for reviewing data and ADA call.

3:50 PM

Structural Health Monitoring of Adhesively Bonded Lap-Joints During Fatigue Testing

---**Oleksii Karpenko**, Gerges Dib, Lalita Udpa, and Satish Udpa, Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48864; Ermias Koricho, Anton Khomenko, and Mahmoodul Haq, Composite Vehicle Research Center, Lansing, MI 48910

---The requirement for reduced structural weight and increasing demand for reconfigurable modular structures have driven the development of adhesively bonded joints. However, a major issue preventing their full acceptance is the initiation of premature failure in the form of a disbond between adherends, mainly due to fatigue, manufacturing flaws or impact damage. In this work we demonstrate the integrated approach for in-situ monitoring of degradation of the adhesive bond in the GFRP composite lap-joint using ultrasonic guided waves and dynamic measurements from strategically embedded FBG sensors. Guided waves are actuated with surface mounted piezoelectric elements and mode tuning is used to provide high sensitivity to parameters of the adhesive layer. Composite lap-joints are subjected to fatigue loading, and data from piezoceramic and FBG sensors are collected at regular intervals to evaluate the progression of damage. Additionally, ultrasonic C-scans are taken to provide the full image of the bonded area. Results demonstrating the feasibility of the proposed monitoring technique to determine the post-damage residual capacity of lap-joints will be presented.

4:10 PM

Parametric Study Using Modal Analysis of a Bi-Material Plate with Defects
---**Shane A. Esola** and Antonios Kontsos, Drexel University, Theoretical & Applied Mechanics Group, Department of Mechanical Engineering & Mechanics, Philadelphia, PA 19104; Ivan Bartoli, Drexel University, Department of Civil, Architectural, & Environmental Engineering, Philadelphia, PA; Suzanne E. Horner and James Q. Zheng, U.S. Army, Program Executive Office – Soldier, Fort Belvoir, VA 22060

---Global vibrational method feasibility as a non-destructive inspection tool for multi-layered composites is evaluated using a simulated parametric study approach. A finite element model of a composite with simple geometry consisting of two isotropic layers of dissimilar materials is constructed as the representative test subject. Next, artificial damage is inserted according to systematic variations of the defect morphology parameters. A free-vibrational modal analysis simulation is executed for pristine and damaged plate conditions. Finally, resultant mode shapes and natural frequencies are extracted, compared and analyzed for trends. Though other defect types may be explored, the focus of this research is on interfacial delamination and its effects on the global, free-vibrational behavior of a composite plate.---Funding for this effort is provided by the U.S. Army Program Executive Office – Soldier.

4:30 PM

Meso-Scale Imaging of Composite Materials
---**Robert Grandin**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---The performance of composite materials is controlled by the interaction between the individual components as well as the mechanical characteristics of the components themselves. Geometric structure on the meso-scale, where the length-scales are of the same order as the material granularity, plays a key role in controlling material performance and having a quantitative means of characterizing this structure is crucial in developing our understanding of NDE technique signatures of early damage states. High-resolution computed tomography (HRCT) provides an imaging capability which can resolve these structures for many composite materials. Coupling HRCT with three-dimensional physics-based image processing enables quantitative characterization of the meso-scale structure. Taking sequences of these damage states provides a means to structurally observe the damages evolution. We will discuss the limits of present 3DCT capability and challenges for improving this means to rapidly generate structural information of a composite and of the damage. In this presentation we will demonstrate the imaging capability of HRCT.---This material is based on work supported by the Army Research Laboratory as part of cooperative agreement number W911NF0820036 at the Center for Nondestructive Evaluation at Iowa State University.

Session 22

SESSION 22
MICROSTRUCTURE
Leonard J. Bond, Chairperson
Cottonwoods-Firs

1:30 PM **The Effect of Martensitic Stainless Steel Microstructure on the Ultrasonic Inspection of Turbine Runner Joints**
---Hamid Habibzadeh Boukani, Samir Mourad Chentouf, Martin Viens, and Antoine Tahan, École de technologie supérieure (ÉTS), Mechanical Engineering Department, Montréal, Québec, Canada; Martin Gagnon, Institut de recherche d'Hydro-Québec (IREQ), Varennes, Québec, Canada

1:50 PM **The Interpretation of On-Load Data for Power Station Creep Life Monitoring**
---**Joseph Corcoran** and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Peter Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221-0070

2:10 PM **A Magneto Optical Sensor Technique for the Detection of Micro Surface Defects**
---**Robert Stegemann**, Matthias Pelkner, and Marc Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany

2:30 PM **Voigt, Reuss, Hill, and Self-Consistent Techniques for Modeling Ultrasonic Scattering**
---Christopher M. Kube and Joseph A. Turner, University of Nebraska, Mechanical and Materials Engineering, NE 68588

2:50 PM **Multi-Mode RF Sensor for Moisture Analysis of a High Pressure Gasket Material**
---**Gene Bogdanov** and Reinhold Ludwig, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, Worcester, MA 01609; Jason Wiggins and Ken Bertagnolli, US Synthetic, Orem, UT 84058

3:10 PM ***Break***

3:30 PM **Microstructural Characterization of Nickel-Iron Based Superalloy by Non-Destructive Evaluation Techniques**
---**Vidhi V. Acharya**, Indus Institute of Technology & Engineering, Indus University, Department of Metallurgical Engineering, Ahmedabad, Gujarat, India; G. V. S. Murthy, CSIR-National Metallurgical Laboratory, Materials Science Division, Jamshedpur, 831007 Jharkhand, India

3:50 PM **Relationship Between Near-Surface Ultrasonic Shear-Wave Backscatter and Grain Size in Metals**
---**Brady J. Engle**[1,2], Frank J. Margetan[1], and Leonard J. Bond[1,2,3]; [1]Center for NDE, 1915 Scholl Road, 111 ASC II, Iowa State University, Ames, IA 50011; [2]Department of Aerospace Engineering, 1200 Howe Hall, Iowa State University, Ames, IA 50011; [3]Department of Mechanical Engineering, 2025 Black Engineering, Ames, IA 50011

4:10 PM **Nondestructive Characterization of Pipeline Materials**
---**Brady J. Engle**[1,2]; Lucinda Smart[1,3,4]; and Leonard J. Bond[1,2,3]; [1]Center for NDE, 1915 Scholl Road, 111 ASC II, Iowa State University, Ames, IA 50011; [2]Department of Aerospace Engineering, 1200 Howe Hall, Iowa State University, Ames, IA 50011; [3]Department of Mechanical Engineering, 2025 Black Engineering, Ames, IA 50011; [4]Kiefner and Associates, 1608 S Duff Ave, Suite 400, Ames, IA 50010

4:30 PM **Microstructure Characterization of Macro-Defects in 13Cr-4Ni Cast Martensitic Stainless Steels**
---**Shilan Meimandi** and Philippe Bocher, École de Technologie Supérieure, Mechanical Engineering Department, Montréal, QC, Canada; Denis Thibault, Institut de Recherche d'Hydro-Québec (IREQ), Varennes, QC, Canada; Yves Verreman, École Polytechnique de Montréal, Mechanical Engineering Department, Montréal, QC, Canada

4:50 PM **Crack Closure and Crack Trajectory Tortuosity as Parameters of Vibrothermographic Heating**
---**Tyler Lesthaeghe**, Jyani Vaddi, Lucas Koester, Ashraf Bastawros, William Q. Meeker, and Stephen D. Holland, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

1:30 PM

The Effect of Martensitic Stainless Steel Microstructure on the Ultrasonic Inspection of Turbine Runner Joints

---**Hamid Habibzadeh Boukani**, Samir Mourad Chentouf, Martin Viens, and Antoine Tahan, École de technologie supérieure (ÉTS), Mechanical Engineering Department, Montréal, Québec, Canada; Martin Gagnon, Institut de recherche d'Hydro-Québec (IREQ), Varennes, Québec, Canada

---Martensitic stainless steel runners are widely used in the hydroelectric turbine industry because of their good mechanical properties, cavitation and corrosion resistance. The high downtime cost and limited in-service inspection possibility of these turbine runners increase the need for accurate fatigue models to estimate the life of these equipment. One of the key inputs of these models is the distribution of flaw size and their location near highly stressed area. The critical area is generally located near the welded joint and flaw sizes are estimated using the outcome of nondestructive inspection. In such case, more reliable NDT results will lead to less uncertainty in the life estimation. Hence avoid either unexpected failure during service or non-essential down time for unnecessary inspections. Turbine runner welded joints are inspected using ultrasonic refracted shear waves. Considering the dependence of the refracted angle to the shear wave velocity in the material as well as its role in the precision of defects' localization, the martensitic microstructure effect on sound wave velocity need to be accurately known. Furthermore, attenuation coefficient, which affects reflected signal amplitude, is an essential information for the evaluation of defect size which is also dependent on microstructure. In this context, ultrasonic shear wave properties dependence on metallurgical characteristics of martensitic stainless steel was studied. Our objective is to obtain better POD from a more accurate characterization of received indications.---This research received funding from The Natural Sciences and Engineering Research Council of Canada (NSERC) and Fonds de recherche du Québec – Nature et technologies (FQRNT). The authors also gratefully acknowledge use of the services and facilities of Institut de recherche d'Hydro-Québec (IREQ) and ANDRITZ Hydro Ltd.

1:50 PM

The Interpretation of On-Load Data for Power Station Creep Life Monitoring
---**Joseph Corcoran** and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Peter Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221-0070

---For practical engineering applications creep occurs in an inherently harsh, high-temperature environment. There is a strong industry demand for continuous measurements to allow a better understanding of component integrity in a situation where outages allowing inspection are infrequent; in the UK the expected inspection interval is 2+ years. The generation of frequent in-situ measurements allows the time increment between measurements to be made sufficiently small to make it feasible to monitor rate of change parameters accurately. A permanently installed Potential Drop Strain Sensor has been previously presented and is the subject of continuing site trials. The sensor measures a transfer resistance between electrodes which are permanently attached to the component surface. The transfer resistance is then sensitive to the distance between electrodes and therefore accumulated strain. The well-known continuum damage approach introduced and developed by Rabotnov and Kachanov can be utilized for remnant life predictions. It has long been realized that using such analysis, together with the now possible frequent strain measurements allows life assessment that is a) near-continuous and b) does not rely on the extrapolation of lab data to estimated site conditions and material properties. This paper will review these strain based calculations and apply them to the case of a multi-axially stressed power station component. The Potential Drop Strain Sensor can also be applied in a situation where micro- and macro-cracking is expected such as in the heat affected zone of welds. In this situation the measurement is known to be sensitive to a combination of both cracking and localized strain. An understanding of how the resistance changes with strain can be utilized to segment strain related changes from those associated with cracking. It will be shown that localized damage at a weld can be identified and that rate changes can be used for early warning of failure.

2:10 PM

A Magneto Optical Sensor Technique for the Detection of Micro Surface Defects
---**Robert Stegemann**, Matthias Pelkner, and Marc Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany

---The early detection of micro cracks and material discontinuities in non-destructive testing (NDT) requires high-resolution sensor techniques. Usually, the magnetic flux leakage (MFL) detection is performed by relatively bulky magnetic inspection sensors. Consequently, their spatial resolution is limited due to an unavoidable slight sensor lift off and the size of the probe's sensing area. We present in this paper a new method for MFL detection using a magneto-optical (MO) hand-held microscope. The principle of MO method is based on Faraday-effect. Its sensor coating works in direct contact with the specimen and magnetic fields are transformed into an intensity distribution. The sensor coat has a dynamic field range between ±0.05 and ±2 kA/m and a lateral optical resolution of approx. 15 µm. Comparative measurements using a high-precision 3-axial magnetic field GMR (giant magneto resistance) sensor, verify the outstanding capability of the MO microscope regarding spatial resolution of magnetic fields. The measurements were performed on an intentionally magnetized steel plate with small artificial defects of known geometries in the µm-regime. The defects were custom-made by electrical discharge machining (EDM) and their sizes were measured optically. The MO technique is direct, quick and provides high-resolution 2D images. Similar to other electromagnetic non-destructive inspection techniques only the normal component of the MFL is measured. In contrast, the 3D-GMR multi-line measurements are more time-consuming and the results have a lower spatial resolution. Its high field sensitivity and the ability to measure all three directions of the MFL maintain an advantage. We report that the MO and GMR sensor techniques are feasible instruments for high resolution magnetic field detection.

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Voigt, Reuss, Hill, and Self-Consistent Techniques for Modeling Ultrasonic Scattering

---Christopher M. Kube and Joseph A. Turner, University of Nebraska, Mechanical and Materials Engineering, NE 68588

---The amount of ultrasonic scattering in metals depends on the degree of single-crystal elastic anisotropy present within the grains and the randomness of grain orientations. These two factors cause point-to-point stiffness deviations causing acoustic impedance differences at grain boundaries. The local stiffness deviations allow for the use of perturbation techniques to model scattering based experimental phenomenon such as backscatter, attenuation, and diffusivity. Perturbation techniques, such as the Keller and smoothing approximations, evaluate the deviation of the local elastic stiffness tensor from an orientation-averaged stiffness tensor representing the stiffness of the ensemble or homogenized medium. The local elastic stiffness tensor is well known and is defined for all crystal symmetries. Conversely, the stiffness tensor representing the ensemble medium has traditionally been defined predominantly by the nonunique Voigt average. The nonuniqueness has motivated the use of alternative techniques to define the elastic stiffness properties of the ensemble medium. This presentation will give a comparison between the different averaging schemes used to define the ensemble medium. The variation of backscatter, attenuation, and diffusivity parameters will be discussed. Experimental attenuation measurements are compared with theoretical models utilizing the various schemes. The self-consistent Eshelby scheme derived by Hershey and Kroner is endorsed and supported by these results.

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Multi-Mode RF Sensor for Moisture Analysis of a High Pressure Gasket Material
---**Gene Bogdanov** and Reinhold Ludwig, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, Worcester, MA 01609; Jason Wiggins and Ken Bertagnolli, US Synthetic, Orem, UT 84058

---We have previously reported on a nondestructive moisture analysis technique to inspect high-pressure gaskets. During the compaction process of creating synthetic diamond tables, these gaskets seal the cubical pressure cell and transmit pressure within high-performance presses. Excess moisture in gaskets increases the chance of explosive decompression and shortens the life of the press anvils. Our initial approach places the gasket in a radio-frequency resonator operating near 220 MHz. This sensor is able to detect minute changes in the dielectric loss tangent, whose value was determined to be approximately 0.005 for dry material. The moisture content of a dry gasket is about 0.5%, measured by weight loss after drying. Although this electromagnetic sensing approach was successful in correlating loss tangent to moisture content, it was disproportionately sensitive to moisture absorbed from the air relative to that remaining from the drying process. It was hypothesized that absorbed moisture is concentrated in a relatively thin layer near the surface of the gasket. Working from this hypothesis, this paper proposes a new multi-mode cavity resonator sensor. Different resonant modes apply different electric field patterns to the sample under test. Given sufficiently accurate measurements, we expect to discern the interior loss tangent from that near the surface. Our paper presents simulations and experimental results for this new sensor.

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Microstructural Characterization of Nickel-Iron Based Superalloy by Non-Destructive Evaluation Techniques

---**Vidhi V. Acharya**, Indus Institute of Technology & Engineering, Indus University, Department of Metallurgical Engineering, Ahmedabad, Gujarat, India; G. V. S. Murthy, CSIR-National Metallurgical Laboratory, Materials Science Division, Jamshedpur, 831007 Jharkhand, India

---The present industrial scenario requires that any engineering structure has to be designed considering stability of several parameters at the operating conditions (for e.g., temperature and pressure in Space Shuttle Main engine). Materials choice for any engineering component should be such that it operates safely for reliable function; without failure during service, giving optimum component life. The scarcity of various resources and cost of manufacturing, results in regular maintenance of the engineering structure and evaluation of the integrity of the component at every stage of production. Non-destructive Testing techniques at low and affordable cost help in nonintrusive investigation of the component at regular intervals of the operating stages for many critical applications. Extending life of the present available equipment through Non-Destructive Evaluation techniques is thus very useful; as it helps in the increment of designed component life and also maximizes utilization of the natural resources. Inconel 718 is a Ni-Fe base high strength superalloy, which can be age hardened by precipitation hardening. Inconel 718 in wrought condition contains non-uniform distribution of gamma prime (γ'), gamma double prime (γ''), delta (δ) and carbides in an austenite (γ) matrix. The aim of present investigation is to characterize different microstructural features and the precipitation behavior, evolved through various heat treatments, to correlate them with non-destructive evaluation techniques like DC electrical resistivity and Ultrasonic testing, and hardness. Thus this study in effect can be used as a non-destructive tool for evaluation of the microstructures on aging.

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Relationship Between Near-Surface Ultrasonic Shear-Wave Backscatter and Grain Size in Metals

---**Brady J. Engle**[1,2], Frank J. Margetan[1], and Leonard J. Bond[1,2,3]; [1]Center for Nondestructive Evaluation, 1915 Scholl Road, 111 ASC II, Iowa State University, Ames, IA 50011; [2]Department of Aerospace Engineering, 1200 Howe Hall, Iowa State University, Ames, IA 50011; [3]Department of Mechanical Engineering, 2025 Black Engineering, Ames, IA 50011

---Backscattered ultrasonic microstructural noise can be used to estimate grain size in metals. However for normal-incidence immersion measurements the ring-down of the front-wall echo creates a "dead zone" where backscattered grain noise cannot be quantified. This poses a problem for near-surface grain sizing efforts. In this paper we explore the use of mode-converted 45-degree shear waves for near-surface grain sizing using a water immersion setup. We discuss how to accurately relate grain noise arrival time with depth of sound penetration in the metal. Then for a set of Ni-alloy specimens having near-equiaxed microstructures we correlate various backscattered noise attributes with grain sizes determined from micrographs. These noise attributes include both time-domain and frequency-domain characteristics.---This work is supported by the Pratt & Whitney Center of Excellence at Iowa State University.

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Nondestructive Characterization of Pipeline Materials

---**Brady J. Engle**[1,2]; Lucinda Smart[1,3,4]; and Leonard J. Bond[1,2,3]; [1]Center for Nondestructive Evaluation, 1915 Scholl Road, 111 ASC II, Iowa State University, Ames, IA 50011; [2]Department of Aerospace Engineering, 1200 Howe Hall, Iowa State University, Ames, IA 50011; [3]Department of Mechanical Engineering, 2025 Black Engineering, Ames, IA 50011; [4]Kiefner and Associates, 1608 S Duff Ave, Suite 400, Ames, IA 50010

---There is an extensive network of gas and oil pipelines in operation in the USA, and globally. Some of these pipes have been in operation since the 1950's and '60's. Over the years the classes of steels, and their strength specifications, for pipe have changed, however the costs of replacement are such that older pipes remain in use and it is essential to ensure their continuing safety. For pipelines, it is important that the materials have the structural integrity to withstand the rated pressurization without failure. In-line inspection (ILI) tools or "smart pigs" are sent inside pipes and using magnetic flux leakage (MFL) and/or ultrasound (UT) they nondestructively detect damage such as cracks or metal loss in the pipe materials. This ILI defect information alone, however, is not enough to determine the pressure rating for the safe operation of the pipeline. In order to determine the appropriate pressure rating of a pipeline, it is important to know the strength properties of pipe material along the length of a pipeline. In many cases, the only current method to provide the desired material properties, yield strength, tensile strength, fracture toughness, and transition temperature, is to dig and locally remove some material and destructively test samples. To better predict pipe performance new nondestructive methods that measure the local mechanical properties of the pipeline are needed. The literature has shown that in some cases, the desired properties have been shown to correlate with some types of ultrasonic and electromagnetic data. This paper will provide a review of the current state of the art for both destructive and nondestructive techniques currently used for pipelines, together with a description of the various nondestructive measurements that potentially could be used to estimate the mechanical properties of interest and provide new tools for pipeline assessment which complement the defect data provided by current ILI tools.---This work was supported by the Department of Transportation under Cooperative Agreement #DTPH56-13-H-CAAP07 and performed at the Center for NDE at Iowa State University.

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Microstructure Characterization of Macro-Defects in 13Cr-4Ni Cast Martensitic Stainless Steels

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---The low carbon 13Cr-4Ni cast martensitic stainless steel is used in hydraulic turbine runners for its ideal features which are among others adequate toughness, high hardenability and high strength to sustain high cycle loads in long lifetime operation; but casting includes several types of defects which have detrimental effects on the performance of the produced parts. Several aspects of the casting defects characterization in these steels have not completely been understood. In industry, it is common to evaluate the integrity of cast components by nondestructive testing such as radiography before putting them to service operation. Since Macro-defects, which are detected by X-ray radiography, have irregular and sharp interior geometry, it is difficult to characterize them precisely only by radiography results. Therefore, the relation between X-ray mapping and actual Macro-defects morphologies has been studied by sequential cross sectioning method which is a destructive procedure to establish the complex shape and morphology of defects. Furthermore, metallographic characterization of cast microstructure in 13Cr-4Ni stainless steels has also been performed by several techniques to study chemical composition and texture properties around Macro-defects. Our aim in this project is to characterize cast Macro-defects in martensitic stainless steels based on X-ray radiography outcome.---The authors wish to acknowledge the help and facilities provided by Institut de Recherche d'Hydro-Québec (IREQ) and ALSTOM Canada Inc.

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Crack Closure and Crack Trajectory Tortuosity as Parameters of Vibrothermographic Heating

---**Tyler Lesthaeghe**, Jyani Vaddi, Lucas Koester, Ashraf Bastawros, William Q. Meeker, and Stephen D. Holland, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Vibrothermography, also known as Sonic IR and Thermosonics, is a nondestructive evaluation technique that finds cracks and flaws due to vibration-induced frictional heating. It has long been observed that vibrothermography causes some cracks to heat far more than others. We investigate the relationship between vibrothermographic crack heating and intrinsic crack properties such as crack closure and crack trajectory tortuosity. We demonstrate how closure effects can be factored out, allowing us to examine the effects of other surface parameters such as roughness and tortuosity of the crack trajectory---This material is based on work supported by the Air Force Research Laboratory under Contract #FA8650-10-D-5210, Task Order #023, and performed at Iowa State University. Case # 88ABW-2014-2748.

Session 23

SESSION 23
STRUCTURAL HEALTH MONITORING
Cara A. C. Leckey, Chairperson
Salmon-Snake

1:30 PM **Damage Imaging Using Lamb Waves for SHM Applications**
---**Tadeusz Stepinski**, L. Ambrozinski, and T. Uhl; AGH University of Science and Technology, Faculty of Mechanical Eng. and Robotics, A. Mickiewicza Av. 30, Pl 30-059 Krakow, Poland

2:10 PM **Ultrasonic Damage Localization on a Pipe Under Longitudinal Temperature Gradients**
---**Chang Liu**, Mario Berges, and Irving J. Oppenheim, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213; Joel B. Harley, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213

2:30 PM **Theoretical and Experimental E/M Impedance Spectroscopy and Guided Wave Propagation Study on Thick Plates with Butt Weld**
---**Tuncay Kamas**, Victor Giurgiutiu, and Bin Lin, University of South Carolina, Mechanical Engineering Department, Columbia, SC 29208

2:50 PM **Guided-Waves Technique for Inspecting the Health of Wall-Covered Building Risers**
---**Peter W. Tse**, J. M. Chen, and X. Wan, The Smart Engineering Asset Management Laboratory (SEAM) and the Croucher Optical Nondestructive Testing Laboratory (CNDT), Department of Systems Engineering & Engineering Management, City University of Hong Kong, Hong Kong, China

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3:30 PM **Portable Wireless Ultrasonic Systems for Remote Inspection**
---**ChengHuan Zhong**, Anthony Croxford, and Paul Wilcox, University of Bristol, Mechanical Engineering, Queen's Building, University Walk, Clifton BS8 1TR, United Kingdom

3:50 PM **Structural Health Monitoring of Localized Internal Corrosion in High Temperature Piping for Oil Industry Applications**
---**T. J. Eason**[1], L. J. Bond[1], and M. G. Lozev[2], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]BP Products North America, Refining and Logistics Technology, Naperville, IL 60563

4:10 PM **Novel Transducer for Shear Horizontal Elastic Waves**
---**Bernd Köhler** and Frank Schubert, Fraunhofer IKTS-MD, Maria Reiche Str. 2, Dresden, Germany

4:30 PM **Damage Mapping in Structural Health Monitoring Using a Multi-Grid Architecture**
---**V. John Mathews**, University of Utah, Department of Electrical & Computer Engineering, Salt Lake City, UT 84108

4:50 PM **Quantitative Acoustic Emission Damage Assessment for Structural Health Monitoring in Composite Structures**
---**Dong-Jin Yoon** and Byeong-Hee Han, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea

5:10 PM **Dielectric Characterization of Spaceflight Materials Towards Monitoring of Structural Health**
---**Nathan A. Kleppe** and Nicola Bowler, Iowa State University, Materials Science and Engineering, Ames, IA 50011; Mark A. Nurge, National Aeronautics and Space Administration, Applied Physics Laboratory, Kennedy Space Center, FL 32815

1:30 PM

Damage Imaging Using Lamb Waves for SHM Applications

---**Tadeusz Stepinski**, L. Ambrozinski, and T. Uhl; AGH University of Science and Technology, Faculty of Mechanical Eng. and Robotics, A. Mickiewicza Av. 30, Pl 30-059 Krakow, Poland

---2-D ultrasonic arrays, due to their beam-steering capability and all azimuth angle coverage are a very promising tool for the inspection of plate-like structures using Lamb waves (LW). Contrary to the classical linear phased arrays (PAs) the 2D arrays enable unequivocal defect localization and they are even capable of mode selectivity of the received LWs. Recently, it has been shown that the synthetic focusing (SF) mode applied for 2D arrays is much more effective than the classical phase array mode commonly used in NDT. The SF mode assumes multiple transmissions of elements in a transmitting aperture and off-line processing of the data acquired by a receiving aperture. In the simplest implementation of the technique, only a single multiplexed input and a number of output channels are required, which results in significant hardware simplification compared with the PA systems. On the one hand implementation of the 2D arrays in the SF mode creates additional degrees of freedom during the design of the array topology, which complicates the array design process, on the other hand, it enables designing sparse arrays with performance similar to that of the fully populated dense arrays. In this paper we present a general systematic approach to the design and optimization of imaging systems based on the 2D array operating in the SF mode. We start from presenting principles of the SF schemes applied to LW imaging. Then, we outline the coarray concept and demonstrate how it can be used for reducing number of elements of the 2D arrays. Finally, efficient tools for the investigation and experimental verification of the designed 2D array prototypes are presented. The first step in the investigation is theoretical evaluation performed using frequency-dependent structure transfer function (STF), which enables approximate simulation of an array excited with a tone-burst in a dispersive medium. The dedicated tool for numerical simulations using the local interaction simulation approach (LISA) can also be used for an accurate evaluation of the 2D array beampattern in a specific structure. Finally, we show how scanning laser vibrometer, sensing waves in multiple points corresponding to the locations of the 2D receiving array elements, can be used as a tool for rapid experimental verification of the developed topologies. The presented methods are discussed in terms of the point spread-functions and beam patterns of the resulting imaging architectures and sparse versions of the fully populated topologies will be presented. The effect of apodization applied to the array elements is also investigated. Both simulated and experimental results are included.---This work was financed within the research grant no. 2011/01/B/ST8/07210 “Theoretical basis for structural health monitoring by means of inverse problem solution under uncertainty” financed by the National Science Centre of Poland.

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Ultrasonic Damage Localization on a Pipe Under Longitudinal Temperature Gradients

---**Chang Liu**, Mario Berges, and Irving J. Oppenheim, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213; Joel B. Harley, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213

---Guided wave structural monitoring (SHM) systems are attractive for plate and pipe structures. Practical implementation of long-term guided wave monitoring is often limited by benign variations in environmental and operational conditions. In order to effectively utilize the ever-growing amount of monitoring data from SHM systems, it is useful to develop data-driven methods that can extract variation-robust, damage-sensitive information from guided wave records. Such a method must be able to: (1) process large amounts of data during the monitoring period and then identify changes of interest; (2) compensate for benign variations caused by the environment; and (3) extract a scatter signal produced by damage for further characterization or localization. In prior work, we developed methods based on singular value decomposition (SVD) to extract damage-sensitive features from a batch of ultrasonic records. We showed that in a harsh and complex operating environment, we can clearly identify changes caused by a small scatterer on a plate or a pipe. We also demonstrated that we can use SVD as a baseline removal method for robust scatterer localization, and achieve better localization results than current temperature compensation routines. In this paper, we further investigate the use of SVD to facilitate damage localization on a pipe. We took pitch-catch records from a longitudinal array of PZT transducers on an aluminum pipe segment (L: 1320mm, ϕ: 89mm). During the experiment, we varied the temperature of the pipe in both space and time – we periodically submerged one end of the pipe in ice water for 30 min, and then returned it to the ambient room air environment. We attached a ϕ-15mm grease coupled scatterer during the experiment, and sought to localize it under the complex temperature profile. We performed delay-and-sum localization with SVD robust baseline removal, and compared the result with that obtained using temperature compensation. We show that SVD achieves overall better results. We also show that by utilizing multiple wave arrivals travelling around the pipe, we can greatly reduce the number of transducers needed to successfully localize damage.

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Theoretical and Experimental E/M Impedance Spectroscopy and Guided Wave Propagation Study on Thick Plates with Butt Weld

---**Tuncay Kamas**, Victor Giurgiutiu, and Bin Lin, University of South Carolina, Mechanical Engineering Department, Columbia, SC 29208

---This paper discusses theoretical and experimental analyses of the standing harmonic waves through the electro-mechanical impedance spectroscopy (EMIS) and guided surface acoustic waves (SAW) through the guided wave propagation (GWP) analyses. Both EMIS and GWP analyses have been carried out by utilizing piezoelectric wafer active sensors (PWAS) for in situ structural inspection of a steel plate with butt weld as the weld bead is ground flush. Ultrasonic techniques are commonly used for validation of welded structures in many in-situ monitoring applications, e.g. in off-shore structures, in nuclear and pressure vessel industries and in a range of naval applications. PWAS is recently employed in such ultrasonic applications as a resonator as well as a transducer. EMIS method is utilized for high frequency local modal sensing to determine the dynamic characteristics of PWAS bonded on structural component for in-situ ultrasonics. Rayleigh waves a.k.a., SAW, were generated in relatively thick isotropic elastic plate. Rayleigh waves are a high frequency approximation of the first symmetric (S0) and anti-symmetric (A0) Lamb wave modes. As the frequency becomes very high the S0 and the A0 wave speeds coalesce, and both have the same value. This value is exactly the Rayleigh wave speed and becomes constant along the frequency. EMIS tests for PWAS bonded on thick steel plate are conducted near-field and far-field to weld bead in frequency range of MHz and analyzed in terms of thickness mode. Analytical predictive thickness mode impedance simulations of PWAS bonded on plate-like host structures are presented in corresponding with the experiments. The study is followed with GWP tests through the pitch-catch method along and across the butt weld line. The tuning curve of Rayleigh wave is determined to show the tuning effect of the structure thickness on producing a dominant Rayleigh wave mode. The significant usage of the tuned Rayleigh wave mode is essentially discussed for the applications in the in-situ inspection of relatively thick structures with butt weld such as naval offshore structures. The paper ends with summary, conclusions and suggestions for future work.---Support from National Science Foundation Grant # CMS-0925466; Office of Naval Research #N00014-11-1-0271, Dr. Ignacio Perez, Program Manager; are thankfully acknowledged.

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Guided-Waves Technique for Inspecting the Health of Wall-covered Building Risers

---**Peter W. Tse**, J. M. Chen, and X. Wan, The Smart Engineering Asset Management Laboratory (SEAM) and the Croucher Optical Nondestructive Testing Laboratory (CNDT), Department of Systems Engineering & Engineering Management, City University of Hong Kong, Hong Kong, China

---Guided-waves inspection (GW) technique proves to be an effective method for inspecting pipe defects. However, as of today, the technique used for inspecting pipe structures has not attracted much market attention because of insufficient field tests and traceable records with proven results in commercial applications. In this paper, it presents the results obtained by using GW technique to inspect the defects occurred in real and operating building gas risers. The purpose of having risers is to deliver nature gas from the building external piping system to each household unit of the building. The risers extend from the external wall of the building, penetrate thorough the concrete, into each unit's kitchen or bathroom. Similar to in-service pipes, risers are prone to corrosion due to water leaks into the concrete wall. However, the corrosion occurs in the section of riser, which is covered by the concrete wall, is difficult to be inspected by conventional techniques. Hence, GW technique was employed. The effectiveness of GW technique was tested by laboratory and on-site experiments using real risers that part of their lengths are covered by concrete walls. The experimental results show that GW can partially penetrate thorough the riser's section that is covered by wall. The health of the section of risers that are covered by walls can be determined by the reflected wave signals generated by the discontinuity exited inside the wall covered section. Based on the reflected wave signal, one can determine the health of the risers especially on the section that is covered by concrete wall.

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Portable Wireless Ultrasonic Systems for Remote Inspection
---**ChengHuan Zhong**, Anthony Croxford, and Paul Wilcox, University of Bristol, Mechanical Engineering, Queen's Building, University Walk, Clifton BS8 1TR, United Kingdom

---The weight and power storage of conventional wire and active wireless systems limit their applications to some engineering structures such as wind turbines and aerospace structures. In this paper, a passive wireless system for remote ultrasonic inspection is demonstrated. The wireless interface is based on electromagnetic coupling between three coils, one of which is physically connected to an ultrasonic piezoelectric transducer and embedded in or attached to the structure, while the other two are in a separate probing unit. A portable inspection wand and embeddable sensors are developed for large-area impact damage detection in composite. In addition, the system has been integrated with unmanned aerial vehicle (UAV) for remote inspection.

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Structural Health Monitoring of Localized Internal Corrosion in High Temperature Piping for Oil Industry Applications

---**T. J. Eason**[1], L. J. Bond[1], and M. G. Lozev[2], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]BP Products North America, Refining and Logistics Technology, Naperville, IL 60563

---Crude oil is becoming more corrosive with higher sulphur concentration, chloride concentration, and acidity. The increasing presence of naphthenic acids in oils with various environmental conditions at temperatures between 150°C and 400°C can lead to different degradation morphologies in refineries that are uniform, non-uniform, or localized pitting. Improved corrosion measurement technology is needed to better quantify the integrity risk associated with refining crude oils of higher acid concentration. This paper first reports a consolidated review of the state-of-the-art of internal corrosion inspection technology for piping. The advantages and disadvantages of various acoustic, optic, electromagnetic, radiographic, ultrasonic, and other technologies are discussed to establish the foundation for new work in structural health monitoring for localized internal corrosion in high temperature piping. An approach under investigation is to employ flexible ultrasonic thin-film piezoelectric transducer arrays fabricated by the sol-gel manufacturing process for monitoring localized internal corrosion at high temperatures up to 400°C. Initial work will investigate a POD type analysis of a sol-gel transducer using various time of flight thickness calculation algorithms on flat calibration blocks of varied thickness. A statistical approach is used to characterize the performance of the various thickness algorithms. Future work will be discussed.

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Novel Transducer for Shear Horizontal Elastic Waves
---**Bernd Köhler** and Frank Schubert, Fraunhofer IKTS-MD, Maria Reiche Str. 2, Dresden, Germany

---The application of horizontally polarized shear waves is advantageous in NDT and in guided elastic wave SHM, because this wave type do not show mode conversion when reflected at surfaces (parallel to the incident plane). Therefore in NDT the echo signals are relatively easy to interprete. Also leaky radiation into fluids is suppressed, and this is connected with less energy loss and larger range of the application. In plates the lowest index horizontal plate wave (SH0) shows no dispersion and is therefore best suited for SHM and for NDT of pipes in areas difficult to access. Horizontal polarized waves can be excited directly in the material by electromagnetic transducers (EMAT). These transducers are relatively large and do not work on nonconductive materials. Piezoelectric transducers have to be coupled to the surface by glue or by a high viscosity liquid to be able to transfer the shear forces. Moreover, conventional NDT shear transducers contain large seismic masses. Piezoelectric fiber patch (PFP) materials are well known in adaptronics. As shown previously by several authors, it is also possible to modify them for excitation and detection of symmetric and antisymmetric lamb modes in plates, allowing SHM with guided elastic waves. Today horizontal polarized modes are excited and detected only as by product of PFP excited An- und Sn-modes. They are essentially edge waves of these standard PFP transducers. Tis paper describes a concept for a special SH transducer on the basis of PFP. The goal of the concept is the excitation of pure SH plate waves. Simulations on the basis of the Elastodynamic Finite Integration Technique (EFIT) show, that the modes can be exited successfully by this type of transducer. The implications for the guided elastic wave monitoring are discussed.

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Damage Mapping in Structural Health Monitoring Using a Multi-Grid Architecture
---**V. John Mathews**, University of Utah, Department of Electrical & Computer Engineering, Salt Lake City, UT 84108

---This paper presents a multi-grid architecture for tomography-based damage mapping of composite aerospace structures. The system employs an array of piezo-electric transducers bonded on the structure. Each transducer may be used as an actuator as well as a sensor. The structure is excited sequentially using the actuators and the guided waves arriving at the sensors in response to the excitations are recorded for further analysis. The sensor signals are compared to their baseline counterparts and a damage index is computed for each actuator-sensor pair. These damage indices are then used as inputs to the tomographic reconstruction system. The approach of this paper differs from past work in many ways. First, preliminary damage maps are reconstructed on multiple coordinate grids defined on the structure. These grids are shifted versions of each other where the shift is a fraction of the spatial sampling interval associated with each grid. These preliminary damage maps are then combined to provide a reconstruction that is more robust to measurement noise in the sensor signals and the ill-conditioned problem formulation for single-grid algorithms. Second, the system detects defective sensors through an analysis of the sensor signals, and therefore is robust to isolated faulty sensors on the structure. Third, unlike most traditional approaches that employ tonal excitation, the system of this paper uses broadband excitation. Finally, the system recognizes that the reliability of the calculation of most damage indices available in the literature vary with the distance between the actuator and sensor, and the algorithm is tuned appropriately to account for the effect of path length on the measured damage indices. The paper contains detailed derivations and algorithm issues related to (1) design of excitation signals; (2) choice of damage indices and their properties; (3) identification of defective sensors from sensor data; and (4) experimental results on a composite structure with complexity that is representative of aerospace structures. Experimental results provided in the paper demonstrate that for sufficiently high sensor densities, the algorithm of this paper is capable of providing damage detection and characterization with comparable or better accuracy than traditional C-scan and A-scan-based ultrasound non-destructive inspection systems.---This work is supported in part by the Air Force Office of Scientific Research (Award No. FA95501210291) and the National Aeronautics and Space Administration (Award No. NNM13AA12G).

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Quantitative Acoustic Emission Damage Assessment for Structural Health Monitoring in Composite Structures

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---Structural health management is one of the major issues for monitoring and assessing the integrity of large structures like a huge wind turbine blade. There are two key contributors as non-destructive technology point of view. One is how to detect defects inside more exactly after manufacturing of each component. The other one is how to monitor its integrity during operation. So, it is very important to detect and locate the damages early in the structures, since it can tell a symptom of damage propagation before catastrophic failure. Recently, this kind of technique, that is an in-situ monitoring of integrity of materials or structures, becomes increasingly popular for monitoring the conditions of large structures like a wind turbine blade. In this study, acoustic emission technology was applied to assess the damage in the wind turbine blade. A new source location method was applied which has developed an algorithm with energy contour mapping concept. First, we acquired an energy based contour map database for tested blade section which is a part of full scale wind turbine blade of 3 MW capacity. And then, we measured the activities and the intensity of each arrival signal for several types of damage sources. We also have tried to solve the existent source location problem for hybrid composite blade consisting of GFRP/PVC/epoxy/wood materials. So, we focused on enhancing a source location method with energy contour map which is developed already, and to develop a new damage index for more clear damage identification. For damage indexing, we found the correlation between corresponding energy and distance from source. Then, after calculating the location of damage source, we can do more quantitative assessment using pre-acquired damage indexing. Consequently, the applicability of new source location method was confirmed by comparison of the result of source location and experimental damage location. From several experimental results, new suggested method of damage index identification showed very good performance for assessment of damages in the composites structures.

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Dielectric Characterization of Spaceflight Materials Towards Monitoring of Structural Health

---**Nathan A. Kleppe** and Nicola Bowler, Iowa State University, Materials Science and Engineering, Ames, IA 50011; Mark A. Nurge, National Aeronautics and Space Administration, Applied Physics Laboratory, Kennedy Space Center, FL 32815

---As commercial space travel increases, the need for reliable structural health monitoring to predict possible weaknesses or failures of structural materials also increases. Monitoring of these materials can be done through the use of dielectric spectroscopy by comparing permittivity or conductivity measurements performed on a sample in use to that of a pristine sample from 100 µHz to 3 GHz. Fluctuations in these measured values or of the relaxation frequencies, if present, can indicate chemical or physical changes occurring within the material and the possible need for maintenance/replacement. In this work, we establish indicative trends that occur due to changes in dielectric spectra during accelerated aging of various high-performance polymeric materials (EVOH, Kapton, PEEK, PPS, PVDF, UHMWPE, and wear-resistant nylon). Uses for these materials range from electrical insulation and protective coatings to windows and air- or space-craft parts that may be subject to environmental damage over long-term operation. Samples were prepared by thermal exposure and, separately, by ultraviolet/water-spray cyclic aging. The aged samples showed statistically-significant trends of either increasing or decreasing real or imaginary permittivity values, relaxation frequencies, conduction or the appearance of new relaxation modes. These results suggest that dielectric testing offers the possibility of nondestructive evaluation of the extent of age-related degradation in these materials.---
This work was supported by a NASA Space Technology Research Fellowship under cooperative agreement number NNX13AL81H.

THURSDAY

THURSDAY, JULY 24, 2014

	Session 24 Materials Characterization *Peregrines*	Session 25 Laser Ultrasonics *Cottonwoods-Firs*	Session 26 Composites II *Pines-Willows*	Session 27 Modelling *Salmon-Snake*
8:30 AM				
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9:10				
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10:10	COFFEE BREAK			
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12:10 PM	LUNCH			

Session 28 – POSTERS – 1:30 – 3:10 PM – *Hawk*

	Session 29 Radiography II *Cottonwoods-Firs*	Session 30 Signal Processing *Peregrines*	Session 31 Robotics *Pines-Willows*	Session 32 Nonlinear *Salmon-Snake*
3:10	COFFEE BREAK			
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Session 24

SESSION 24
MATERIALS CHARACTERIZATION
Eric Lindgren and John Aldrin, Co-Chairpersons
Peregrines

8:30 AM **Desirements and Requirements for NDE for Characterization: An AFRL Perspective**
---**Eric Lindgren**, Materials State Awareness and Supportability Branch, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433-7816

9:10 AM **Model-Based Inversion of Electromagnetic Signals for Crack Characterization**
---Siamack Mazdiyasni and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433; **Eric B. Shell**, Wyle, Dayton, OH 45440; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401

9:30 AM **Damage Localization Using Ultrasonic Methods in Multi-Layered Metallic Structures**
---**Deborah L. Hopkins** and Marvin R. Datuin, BERCLI Corp., NDE R&D, Berkeley, CA 94703; John C. Aldrin, Computational Tools, Gurnee, IL 60031; David S. Forsyth, Mark F. Warchol, and Lyudmila V. Warchol, Texas Research Institute, NDE SHM Division, Austin, TX 78733-6201; Eric A. Lindgren and Charles F. Buynak, Air Force Research Laboratory (ARL/RXCA), Wright-Patterson AFB, OH 45433

9:50 AM **Separation and Analysis of Incident and Scattered Waves in Angle-Beam Wavefield Data**
---**Alexander J. Dawson**, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, NW, Atlanta, GA 30332-0250

10:10 AM ***Break***

10:30 AM **Computational NDE as an Integrated Component of ICMSE**
---**James L. Blackshire**, Air Force Research Laboratory, AFRL/RXCA, 2230 Tenth Street, Wright-Patterson AFB, OH 45433

11:10 AM **Resonance Ultrasound Spectroscopy Forward Modeling and Inverse Characterization of Nickel-Based Superalloys**
---**Eric Biedermann** and Leanne Jauriqui, Vibrant Corp., Albuquerque, NM 87113; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Brent Goodlet, Tresa Pollock, and Chris Torbet, University of California, Santa Barbara, CA 93106; Siamack Mazdiyasni, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433

11:30 AM **Case Study on NDE Characterization Metrics for Optimization, Validation and Quality Control**
---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, Palm Beach Garden, FL 33418-7161; Harold A. Sabbagh, Victor Technologies LLC, Bloomington, IN 47407-7706; Eric Shell, Wyle, Dayton, OH 45440-3638; Jeremy S. Knopp and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433

11:50 AM **Ultrasonic Wall Loss Monitoring of Rough Surfaces**
---**Attila Gajdacsi** and Frederic Cegla, Imperial College, Mechanical Engineering, London, United Kingdom

12:10 PM ***Lunch***

8:30 AM

Desirements and Requirements for NDE for Characterization: An AFRL Perspective

---**Eric Lindgren**, Materials State Awareness and Supportability Branch, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433-7816

---Nondestructive evaluation (NDE) has a significant role in the management of the safety and availability of US Air Force aircraft for both structures and propulsion systems. Current use of NDE focuses on the ability to detect damage and/or material features of interest. This is a required capability that is validated by probability of detection curves when using damage tolerance analysis (DTA) for locations where slow crack growth is the dominant failure mechanism. Therefore, this method is used for most metallic structures. For composite materials where the damage progression cannot yet be predicted accurately, NDE is still used in the management of safety of structures made from these materials. However, it is recognized that the current use of NDE methods for all types of materials is costly and time-consuming, as the inspections are driven by time-based or event-driven scheduling. To address the high cost and time to perform required inspections for aging systems and for new systems with non-metallic materials, the US Air Force is seeking to implement Condition-based Maintenance (CBM). This objective requires that the condition of a material and/or damage be characterized in terms of location and size to enable maintenance to be performed only when required and not according to pre-existing time schedules. In addition, NDE-based characterization can be used to verify tailored microstructure to obtain desired material properties without resorting to destructive testing during the manufacturing and processing of new materials. To realize this objective, the use of NDE for characterization must be accompanied by methods to provide statistical metrics of performance of the characterization process. The performance metrics will be used in the calculation of losing integrity which is the metric used by the US Air Force to ensure safety. This presentation provides an overview of the role of NDE in the current approach to ensure safety of USAF aircraft and the capabilities that must be realized by NDE methods to realize the objective of full materials and/or damage characterization regardless of scale for all US Air Force relevant materials. The presentation highlights several current activities being executed within the Air Force Research Laboratory to realize this objective as well as several remaining challenges that must be addressed to enable eventual transition of this capability to a production-based environment.

9:10 AM

Model-Based Inversion of Electromagnetic Signals for Crack Characterization
---Siamack Mazdiyasni and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433; **Eric B. Shell**, Wyle, Dayton, OH 45440; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401

---The objective of this work is to demonstrate and validate robust signal processing algorithms and model-based inversion techniques to characterize length, depth, width and orientation of surface-breaking cracks using eddy current NDE. Model enhancements were made to VIC-3D® to improve control of the field extent and resolution for complex probes with cores. Surrogate models were developed using VIC-3D® simulations with novel interpolation and mixing schemes, and validated at intermediate points. High fidelity automated eddy current data was collected and analyzed to validate baseline modeling capabilities of the differential reflection sensors used in propulsion component inspections. Benchmarking studies demonstrated good agreement between experimental and simulated results. A range of conditions, spanning the expected variations from fielded systems, was included to determine the sensitivity of inspections and models to various physical inspection and defect variations. Among those parameters studied are flaw length, depth, aspect ratio, and profile; liftoff and normality of the probe to the test surface; crack and coil orientation relative to the scan direction; and coil construction variations. The data were analyzed with emphasis on how the processing and sampling of the data would affect flaw sensitivity as well as model agreement. Automated algorithms for signal processing and centering were also implemented to support the inversion process. Model-based inversion results were produced for a wide range of cracks and EDM notches in nickel and titanium alloys. Initial inversion results indicate the potential to accurately size cracks and EDM notches over a wide range of crack and probe orientations. Future work will address a comprehensive test plan to run repeated studies varying the conditions of the eddy current data, the NDE model and inversion algorithm, and verify crack depth estimates through destructive characterization.

9:30 AM

Damage Localization Using Ultrasonic Methods in Multi-Layered Metallic Structures

---**Deborah L. Hopkins** and Marvin R. Datuin, BERCLI Corp., NDE R&D, Berkeley, CA 94703; John C. Aldrin, Computational Tools, Gurnee, IL; David S. Forsyth, Mark F. Warchol, and Lyudmila V. Warchol, Texas Research Institute, NDE SHM Division, Austin, TX; Eric A. Lindgren and Charles F. Buynak, Air Force Research Laboratory (ARL/RXCA), Wright-Patterson AFB, OH 45433

---Results are presented from a highly collaborative project that builds on previous research designed to improve ultrasonic (UT) localization of damage in mutli-layer metallic structures. One of the primary objectives of the project is to test existing acoustic models for cracks around fastener holes, and further develop a model as necessary to achieve the accuracy required for Air Force applications. For the first phase of the project, CIVA modeling results have been compared to ultrasonic measurements on aluminum plates with fatigue cracks and EDM notches at different locations around through-thickness holes. Variables include the diameter of the holes, length/width of notches/cracks, position of notches/cracks on the hole (angle with respect to the probe) and position in depth (surface, mid bore, backwall and through thickness). Baseline measurements have also been made on side-drilled and spherical-tip holes. Modeling challenges include accurately accounting for reflections arising from the cracks and the specimen geometry, mode conversion, contact conditions between fasteners and fastener holes, and reflection/transmission coefficients at interfaces between layers. For the ultrasonic measurements, a spherically focused 10-MHz probe is positioned to generate 45-degree shear waves in the plate. High-resolution UT data are compared to modeling results obtained using both CAD and CIVA generated models of the test specimens. The models are evaluated and compared in terms of their ability to reproduce UT responses from specimen and crack/notch features.---This work is Delivery Order 022 on the Research Initiatives for Materials State Sensing Program, funded by the Materials and Manufacturing Directorate of the Air Force Research Laboratory.

9:50 AM

Separation and Analysis of Incident and Scattered Waves in Angle-Beam Wavefield Data

---**Alexander J. Dawson**, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, NW, Atlanta, GA 30332-0250

---The measurement of ultrasonic signals over a 2-D rectilinear grid resulting from a fixed source, referred to as wavefield imaging, is a powerful tool for visualizing wave propagation and scattering in plates. Wavefield imaging provides a more complete picture of wave propagation than conventional single-point measurements, but creates more challenges for analysis. This work considers the development of wavefield-based methods for analyzing angle-beam wave propagation and scattering in plates. Methods of analysis focus on the separation of incident and scattered waves with the goal of scatterer characterization. Two methods for wave separation are considered: baseline subtraction and frequency-wavenumber filtering. Baseline subtraction is a technique that is typically applied to in situ measurements between fixed transducers rather than full wavefields, whereas frequency-wavenumber filtering is applied to wavefield data that are finely sampled in both space and time. Baseline subtraction of wavefields, particularly for the frequency range considered here, is sensitive to both specimen alignment and temperature variations, whereas frequency-wavenumber methods are limited in their ability to separate incident and scattered waves traveling in the same direction. This work focuses on investigating and overcoming the challenges to full wavefield baseline subtraction, and compares results to those obtained using frequency-wavenumber techniques. The strengths and weaknesses of the two approaches are compared and contrasted for different types of scatterers.---This work was supported by the Air Force Research Laboratory (AFRL) under Contract No. FA8650-10-D-5210 (Dr. Eric Lindgren, Program Manager).

10:30 AM

Computational NDE as an Integrated Component of ICMSE

---**James L. Blackshire**, Air Force Research Laboratory, AFRL/RXCA, 2230 Tenth Street, Wright-Patterson AFB, OH 45433

---A key area of intense research involves the use of integrated computational materials and manufacturing science and engineering (ICMSE) approaches which can assist in the development, enhancement, and validation of complex engineered material systems. At its core, ICMSE involves material-centric models which synergistically integrate computational tools related to materials development, processing, manufacturing, and property/performance assessment. As an integrated component of ICMSE, NDE modeling can be utilized for in-situ process monitoring applications, material prototype evaluations, and usage monitoring applications, where important connections between NDE signals and material properties can be made in a virtual environment. In the present effort, ultrasonic nondestructive evaluation model results are presented for 2D and 3D elastic wave interactions with realistic and synthetic polycrystalline microstructure systems. Progress towards improved understanding of multi-scattering physics, coherent energy transfer, and wavefront perturbations are discussed, where opportunities for improved microstructure quantification are provided, and an example of integrating computational NDE as a component of the ICMSE paradigm is illustrated.

11:10 AM

Resonance Ultrasound Spectroscopy Forward Modeling and Inverse Characterization of Nickel-Based Superalloys

---**Eric Biedermann** and Leanne Jauriqui, Vibrant Corp., Albuquerque, NM; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Brent Goodlet, Tresa Pollock, and Chris Torbet, University of California, Santa Barbara, Santa Barbara, CA; Siamack Mazdiyasni, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH

---Resonance Ultrasound Spectroscopy (RUS) is a nondestructive evaluation method which can be used to quantify the elastic properties of a wide range of materials by measuring their resonance spectra. Prior work on gas turbine airfoils exposed to high temperature and stress has shown that RUS is capable of measuring corresponding shifts in frequency peaks. The objective of this effort is to enhance RUS measurement models to more precisely connect changes in the resonance frequencies of nickel-based super-alloy material to the macro/microscopic state. RUS models using the finite element method were developed demonstrating the ability to simulate varying elastic properties, grain structures and coatings. A comprehensive test plan was conducted, investigating the effect of exposure to high temperatures and stress for varying part shape and three grain structure classes: single crystals (SX), directionally-solidified (DS) and polycrystalline (PX) structures. New RUS property inversion tools were developed in the program. Inversion using traditional analytical models was enhanced in order to simultaneously estimate varying material properties and changes in part geometry, for example due to creep. Inversion using surrogate models from finite element method (FEM) simulations was also developed, addressing crystal orientation and complex geometries. The inversion results of the elastic properties for the three grain structure classes were found to be in agreement with expectation for cylinders and parallelepipeds. For SX specimens, the importance of addressing varying crystal orientation was demonstrated. For cylindrical DS specimens, it was possible to invert the effective cubic elastic properties over lower frequencies; however, for higher modes, the approximate model was found to break down. Isotropic models were found to be satisfactory for representing PX specimens and achieved good agreement with polycrystalline averaging techniques. By considering a weak deviation from isotropic behavior through including anisotropy and degeneracy terms, a more precise representation of the RUS frequency spectrum could be achieved. The means of inverting ‘changes’ in material properties due to heat treatments was also developed and found to be highly sensitive and less prone to error versus inverting absolute material properties. Results from the studies show sensitivity to apparent global elastic property changes with certain heat treatments; however, it is difficult to precisely connect these changes to the material microstructure state at this time.

11:30 AM

Case Study on NDE Characterization Metrics for Optimization, Validation and Quality Control

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, Palm Beach Garden, FL 33418-7161; Harold A. Sabbagh, Victor Technologies LLC, Bloomington, IN 47407-7706; Eric Shell, Wyle, Dayton, OH 45440-3638; Jeremy S. Knopp and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433

---In prior work, a comprehensive approach was proposed to validate NDE characterization capability that follows the framework of the ‘ahat-versus-a’ model evaluation process for probability of detection (POD) assessment. Recent work has investigated this approach using crack sizing results from eddy current inspection techniques for propulsion systems. Some challenges were found in attempting to use existing POD sets where the crack depth and profile are not precisely known. While such sets are typically adequate for POD evaluation, they do not provide the accuracy needed for NDE characterization assessments. However, there are several data evaluation approaches that can be used to overcome such a lack of knowledge about the crack state, producing results that can be useful beyond validation studies. The objective of this work is to highlight different data analysis strategies and characterization metrics for (1) designing and optimizing NDE characterization techniques, (2) validating NDE characterization performance and (3) ensuring in-service quality control. A case study is introduced based on the estimation of length, depth, width and orientation of surface breaking cracks and EDM notches using eddy current NDE. Results for several specimen sets are presented that indicate some lack of knowledge of the actual crack depth. Rather than discard such data entirely, it is proposed to use it in order to optimize the inversion process. For example, such cracks can be repeatedly scanned at different orientations with different probe, and the inversion process can be designed to minimize the variance in the depth estimates under the varying conditions. To address comprehensive validation going forward, the use of a finite number of real cracks that are destructively characterized in conjunction with a broader EDM notch specimen set is proposed. Long-term, as eddy-current NDE characterization techniques become validated, they are expected to greatly improve the sizing of cracks in both existing and new POD sets. Lastly, inversion metrics are briefly discussed when no prior knowledge of the crack state is available.

11:50 AM

Ultrasonic Wall Loss Monitoring of Rough Surfaces
---**Attila Gajdacsi** and Frederic Cegla, Imperial College, Mechanical Engineering, London, United Kingdom

---Permanently installed ultrasonic thickness monitoring techniques have been shown to be capable of achieving below 100 nanometer standard deviation repeatability under laboratory conditions, far exceeding that of conventional manual ultrasonic inspection techniques. However, it has also been shown that uneven surface conditions that reflect the ultrasonic waves (internal wall roughness) may limit the accuracy of monitoring in practice. Previous studies have reported the uncertainty of ultrasonic measurements taken on different independent realizations of rough surfaces with the same statistical properties. While this is indicative of potential uncertainties, it is important to recognize that real life defect growth (such as corrosion) does not occur in independent instances, but it manifests itself by small random perturbations of the same underlying surface. In real life applications it is often also more important to extract the wall thickness loss trend such as a corrosion rate (rather than the actual wall thickness) from the measurement. This paper therefore introduces a new model for simulating the evolution of gradual backwall morphology changes (as would be encountered due to corrosion processes). This model is used to simulate ultrasonic signals for a large number of changing backwall surfaces. The thickness and thickness trend is then extracted from these signals using a number of common signal processing methods. The mean thickness slope and uncertainty in the extracted slope is then evaluated and compared to the actual values. A new signal processing method is also proposed, which is shown to be an order of magnitude more accurate in estimating wall loss trends than any other evaluated method.

Session 25

Thursday, July 24, 2014

SESSION 25
LASER ULTRASONICS
Jean-Pierre Monchalin and Daniel Levesque, Co-Chairpersons
Cottonwoods-Firs

8:30 AM **Pulsed Laser Generation of Ultrasound in a Metal Plate Between the Melt and Ablation Thresholds**
---**Arthur G. Every**, School of Physics, University of the Witwatersrand, P.O. Wits 2050, South Africa; Zhandos N. Utegulov, Department of Physics, School of Science and Technology, Nazarbayev University, Astana 010000, Kazakhstan; Istvan A Veres, RECENDT Research Center for Non Destructive Testing GmbH, A-4040 Linz, Austria

8:50 AM **Interaction of Ultrasonic Waves with Surface-Breaking Defects**
---**Rachel S. Edwards**, Andrew R. Clough, Mohd H. Rosli, and Francisco Hernandez-Valle, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

9:10 AM **Detection of Hidden Defects Using Near-Field Ultrasonic Enhancement**
---**Andrew R. Clough** and Rachel S. Edwards, University of Warwick, Department of Physics, Coventry, West Midlands, United Kingdom

9:30 AM **Constrained Laser Generated Surface Acoustic Waves: Applications to Thin Film Interface Delamination**
---**Oluwaseyi Balogun**, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137, N. Tech. Drive, Catalysis Building, Room 325, Evanston, IL 60208; Bradley Sherman, Department of Civil and Environmental Engineering, Northwestern University, 2137, N. Tech. Drive, Evanston, IL 60208

9:50 AM **Developing A Laser Shockwave Model for Characterizing Diffusion Bonded Interfaces**
---**James A. Smith**, Jeffrey M. Lacy, and Barry H. Rabin, Idaho National Laboratory, Nuclear Fuels and Materials Division, Idaho Falls, ID 83415-6188

10:10 AM ***Break***

10:30 AM **Inspection of Weld Quality Using Laser Generated Lamb Waves and Wavelet Signal Processing**
---**Lei Yang** and I. Charles Ume, Georgia Institute of Technology, G.W. Woodruff School of Mechanical Engineering, 813 Ferst Drive NW, Atlanta, GA 30332-0405

10:50 AM **Monitoring of Thick Welded Structure Using In-Process Laser Ultrasonic Testing System**
---**Setsu Yamamoto**, Takeshi Hoshi, Takahiro Miura, Jun Semboshi, and Makoto Ochiai, Toshiba Corporation, Power and Industrial Systems Research and Development Center, Yokohama, Kanagawa 235-8523, Japan; Tsuyoshi Ogawa, Yoshihiro Fujita, and Satoru Asai, Toshiba Corporation, Keihin Product Operations, Yokohama, Kanagawa 230-0045, Japan

11:10 AM **On-Line Monitoring of Austenite Microstructure Using Laser Ultrasonics**
---Sujay Sarkar, Fabienne Damoiselet, Louis Satyanarayan, Thierry Peron, Michel Nogues, and Nicolas Legrand, ArcelorMittal, Maizières-lès-Metz, France; **Daniel Lévesque** and Martin Lord, National Research Council Canada, Boucherville, Qc, Canada ; Nicolas Lefaudeux, Imagine Optic, Orsay, France; Jean-Louis Collet, Centre de recherches métallurgiques, Belgium; Nils Naumann, ArcelorMittal Eisenhuttenstadt, Germany

11:30 AM **Automated Laser-Based Barely Visible Impact Damage Detection in Honeycomb Sandwich Composite Structures**
---**Donato Girolamo**, National Institute of Aerospace, Integrated Structural Health Management Laboratory, Hampton, Virginia, 23666; Luca Girolamo, Università degli Studi di Napoli Federico II, Department of Industrial Engineering, Napoli, 80125, Italy; Fuh-Gwo Yuan, North Carolina State University, Department of Mechanical and Aerospace Engineering, Raleigh, NC, 27695

11:50 AM **Internal Defect Inspection Using Ablation Mode Laser Ultrasonics**
---**Sungho Choi** and Sung-Hee Yoon, Department of Mechanical Convergence Engineering, Hanyang University, 222 Wangsimni-ro, Seoungdong-gu, Seoul 133-791, Korea; Kyung-Young Jhang, School of Mechanical Engineering, Hanyang University, 222 Wangsimni-ro, Seoungdong-gu, Seoul 133-791, Korea

12:10 PM ***Lunch***

8:30 AM

Pulsed Laser Generation of Ultrasound in a Metal Plate Between the Melt and Ablation Thresholds

---**Arthur G. Every**, School of Physics, University of the Witwatersrand, P.O. Wits 2050, South Africa; Zhandos N. Utegulov, Department of Physics, School of Science and Technology, Nazarbayev University, Astana 010000, Kazakhstan; Istvan A Veres, RECENDT Research Center for Non Destructive Testing GmbH, A-4040 Linz, Austria

---The generation of ultrasound in a metal plate exposed to nanosecond pulsed laser heating, sufficient to cause melting but not ablation, is treated. Consideration is given to the spatial and temporal profiles of the laser pulse, penetration of the laser beam into the sample, the evolution of the melt pool, and thermal conduction in the melt and surrounding solid. The excitation of the ultrasound takes place over a few nanoseconds, and occurs predominantly within the thermal diffusion length of a micron or so beneath the surface. Because of this, the output of the thermal simulations can be represented as axially symmetric transient radial and normal surface force distributions. The epicentral displacement response at the opposite surface to these forces is obtained by two methods, the one based on the elastodynamic Green's function determined by the Cagniard generalized ray method, and the other using a finite element numerical method. The two approaches are in very close agreement. Numerical simulations are reported of the epicentral displacement response of a 3.12mm thick tungsten plate irradiated with a 4 ns pulsed laser beam with Gaussian spatial profile, at intensities below and above the melt threshold.

8:50 AM

Interaction of Ultrasonic Waves with Surface-Breaking Defects
---**Rachel S. Edwards**, Andrew R. Clough, Mohd H. Rosli, and Francisco Hernandez-Valle, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

---It is well known that surface-breaking defects can be characterized using ultrasonic surface waves. The transmission of the waves in the region of a defect is related to the frequency content of the wave, the sample thickness, and the defect depth, while an enhanced signal is observed close to the defect opening due to several effects, including constructive interference of incident and reflected waves. We present measurements of surface-breaking defects in plates, pipes and billets using non-contact ultrasonic techniques (EMATs and lasers). The use of non-contact transducers allows easy scanning of samples, in order to study defect interactions in both the near- and far-field relative to the defect position. The effect of geometry and position of the defect (for example a straight slot, angled slot, and branched slots) is studied, and compared to the behavior of the methods on real defects in components removed from service. The benefits of the non-contact techniques are highlighted, including the ability to measure separately the in-plane and out-of-plane components of the wave velocity. The scanning approach also gives a simple method of locating defects on the sample surface.---This is a summary of results from ERC grant, NonContactUltrasonic.

9:10 AM

Detection of Hidden Defects Using Near-Field Ultrasonic Enhancement
---**Andrew R. Clough** and Rachel S. Edwards, University of Warwick, Department of Physics, Coventry, West Midlands, United Kingdom

---When an ultrasonic source or detector is scanned over a surface-breaking defect, a large increase in the magnitude of the ultrasonic wave is observed at certain frequencies. For a scanned detector this enhancement is caused by constructive interference between the incident wave and waves that are reflected and mode converted at the defect, and the effect can be used to obtain the position and depth of a defect. This has been shown to be effective at detecting defects that are surface-breaking on the side of the material that is inspected, for both Rayleigh and Lamb surface waves. We show that ultrasonic enhancement from scanning inspection can also be used to detect defects on plates that propagate from the opposite side to the inspection surface, and that this is an effective tool for detecting hidden defects. Scanning inspection is shown to be capable of detecting the presence of multiple defects and is capable of resolving individual defect positions and providing an estimate of the relative sizes of each defect. The technique is also shown to be effective at detecting and characterizing defects in other sample geometries, such as pipework. The mechanism behind this enhancement is attributed to a constructive interference between incident waves and those reflected at the defect, and therefore the enhancement can provide an insight into the interactions that guided waves undergo when interacting with surface-breaking defects.

9:30 AM

Constrained Laser Generated Surface Acoustic Waves: Applications to Thin Film Interface Delamination

---**Oluwaseyi Balogun**, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137, N. Tech. Drive, Catalysis Building, Room 325, Evanston, IL 60208; Bradley Sherman, Department of Civil and Environmental Engineering, Northwestern University, 2137, N. Tech. Drive, Evanston, IL 60208

---This work explores the dynamic delamination of a metallic thin film using high amplitude elastic stresses generated by a pulsed laser source on a constrained surface. The sample configuration consists of a thin copper film attached to a glass substrate and the film is buried under a transparent layer of a thin polymer. Upon illuminating the copper film with a pulsed laser source, high amplitude mechanical stresses are generated by constraining the expanding plasma under the polymer layer. Two regions of interface delaminations are observed. First, stress concentration at the polymer-copper film interface induces the propagation of interfacial cracks. Second, tensile stresses in the polymer film produce delaminations at the copper film/glass interface and tearing cracks in the copper film. Using experimental data and finite element modeling (FEM), we quantify the stress distribution of the constrained thermomechanical source by matching the displacement profiles of surface acoustic waves measured in the far-field to the FEM model, in order to characterize the strength of the thin film interface.

9:50 AM

Developing A Laser Shockwave Model for Characterizing Diffusion Bonded Interfaces

---**James A. Smith**, Jeffrey M. Lacy, and Barry H. Rabin, Idaho National Laboratory, Nuclear Fuels and Materials Division, Idaho Falls, ID 83415-6188

---The US National Nuclear Security Agency has a Global Threat Reduction Initiative (GTRI) which is assigned with reducing the worldwide use of high-enriched uranium (HEU). A salient component of that initiative is the conversion of research reactors from HEU to low enriched uranium (LEU) fuels. An innovative fuel is being developed to replace HEU. The new LEU fuel is based on a monolithic fuel made from a U-Mo alloy foil encapsulated in Al-6061 cladding. In order to complete the fuel qualification process, the laser shock technique is being developed to characterize the clad-clad and fuel-clad interface strengths in fresh and irradiated fuel plates. The Laser Shockwave Technique (LST) is being investigated to characterize interface strength in fuel plates. LST is a non-contact method that uses lasers for the generation and detection of large amplitude acoustic waves to characterize interfaces in nuclear fuel plates. However the deposition of laser energy into the containment layer on specimen's surface is intractably complex. The shock wave energy is inferred from the velocity on the backside and the depth of the impression left on the surface from the high pressure plasma pulse created by the shock laser. To help quantify the stresses and strengths at the interface, a finite element model is being developed and validated by comparing numerical and experimental results for back face velocities and front face depressions with experimental results. This paper will report on initial efforts to develop a finite element model for laser shock.

10:30 AM

Inspection of Weld Quality Using Laser Generated Lamb Waves and Wavelet Signal Processing

---**Lei Yang** and I. Charles Ume, Georgia Institute of Technology, G.W. Woodruff School of Mechanical Engineering, 813 Ferst Drive NW, Atlanta, GA 30332-0405

---Laser/EMAT ultrasonic (LEU) technique combined with Time of Flight (TOF) based method has been shown to be effective for inspecting weld quality in thick structures where the laser generated ultrasounds are bulk waves. However, challenges remain in thin structures where Lamb waves are prominent and TOF method doesn't work. The received signals are very complicated due to the fact that the laser generated Lamb waves are broadband, multi-modal and dispersive. Therefore it is difficult to interpret the received signals. In this work, the laser generated Lamb waves in a defect free plate are first characterized using continuous wavelet transformation (CWT), then different Lamb wave modes are extracted and reconstructed using the inverse CWT. Next the signals received by LEU weld inspection system are decomposed using CWT and inverse CWT to investigate the suitability of different Lamb wave modes for weld quality determination. The attenuation of different modes in laser generated Lamb waves is also studied.

10:50 AM

Monitoring of Thick Welded Structure Using In-Process Laser Ultrasonic Testing System

---**Setsu Yamamoto**, Takeshi Hoshi, Takahiro Miura, Jun Semboshi, and Makoto Ochiai, Toshiba Corporation, Power and Industrial Systems Research and Development Center, Yokohama, Kanagawa 235-8523, Japan; Tsuyoshi Ogawa, Yoshihiro Fujita, and Satoru Asai, Toshiba Corporation, Keihin Product Operations, Yokohama, Kanagawa 230-0045, Japan

---A New concept non-destructive testing technique for thick welded structures using the laser-ultrasonic technique (LUT) has been investigated. Welded structures are usually inspected with contacting ultrasonic transducers after welding, but it needs a time-consuming and expensive work. We have developed a welding in-process testing system, where welded structures are tested during the welding in-process to save time and manufacturing cost. The laser-ultrasonics can generate and detect ultrasounds by using laser beams. So, it can use non-contact inspection technique which is applicable during welding at high temperatures. Bulk longitudinal acoustic waves were generated by Q-switched Nd:YAG laser. Bulk waves were detected by a confocal Fabry-Perot laser interferometer coupled with a Nd:YAG long pulsed detection laser. To improve the sensitivity of LUT, the modified synthetic aperture focusing technique (m-SAFT) was used. The generation and detection points were separated and these points were flexibly defined. The developed method was applied to actual welding procedure as a monitoring system. 150mm thick walled pipes was welded at above 300 degrees C and a defect which located in first layer of 150mm thick weld structure was clearly observed. The result was verified by the piezoelectric ultrasonic testing conducted after the weld process.

11:10 AM

On-Line Monitoring of Austenite Microstructure Using Laser Ultrasonics

---Sujay Sarkar, Fabienne Damoiselet, Louis Satyanarayan, Thierry Peron, Michel Nogues, Nicolas Legrand, ArcelorMittal, Maizières-lès-Metz, France; **Daniel Lévesque** and Martin Lord, National Research Council Canada, Boucherville, Qc, Canada ; Nicolas Lefaudeux, Imagine Optic, Orsay, France; Jean-Louis Collet, Centre de recherches métallurgiques, Belgium; Nils Naumann, ArcelorMittal Eisenhuttenstadt, Germany

---The evolution of austenite during the hot rolling of steel influences the subsequent product microstructure and finally the product property. To achieve higher product quality and productivity on rolling mills, it becomes necessary to measure and possibly feedback control the microstructure on line. A research project initiated in 2009 was aimed at developing a laser-ultrasonic sensor for microstructure evaluation along a hot strip mill, in inter-stands for recrystallization and grain growth kinetics and on the run-out table for phase transformation and final strip microstructure. After validation with laboratory and pilot mill tests, the sensor was recently tested in industrial hot rolling conditions. The laser-ultrasonic sensor has proved its capacity to give good signal quality even in the presence of strip vibrations. Austenite grain size estimates are determined using ultrasonic attenuation with a single-echo approach. A method for the evaluation of grain elongation using the backscattering spectrum was also investigated in this project. Finally potential exploitation of these microstructure measurements for rolling model improvements and mechanical properties of the final product is discussed.

11:30 AM

Automated Laser-Based Barely Visible Impact Damage Detection in Honeycomb Sandwich Composite Structures

---**Donato Girolamo**, National Institute of Aerospace, Integrated Structural Health Management Laboratory, Hampton, Virginia, 23666; Luca Girolamo, Università degli Studi di Napoli Federico II, Department of Industrial Engineering, Napoli, 80125, Italy; Fuh-Gwo Yuan, North Carolina State University, Department of Mechanical and Aerospace Engineering, Raleigh, NC, 27695

---Nondestructive evaluation (NDE) for detection and quantification of defects in composite materials is fundamental in the assessment of the overall structural integrity of modern aerospace systems. Conventional NDE systems have been extensively used to detect the location and size of damages by propagating ultrasonic waves normal to the surface. However they usually require physical contact with the structure and are time consuming and labor intensive. An automated, contactless laser ultrasonic imaging system for barely visible impact damage (BVID) detection in advanced composite structures has been developed to overcome these limitations. Lamb waves are generated by a Q-switched Nd:YAG laser, scanned by a set of galvano-mirrors over a two dimensional grid on the sample surface. The out-of-plane vibrations are measured through a laser Doppler Vibrometer (LDV) at the edges of the scanned area. Multiple ultrasonic wave-fields of the scanned area, each characterized by different incident wavenumbers directions, are reconstructed, singly analyzed, and then superimposed for high-resolution characterization of impact damage in a honeycomb sandwich composite plate. Two methodologies are used for ultrasonic wave-field analysis: Fourier domain analysis method and residual energy-mapping. The Fourier domain analysis is employed for processing the wavefield and estimate spatially dependent wavenumber values, related to discontinuities in the structural domain. The residual energy-mapping algorithm highlights standing waves trapped within damaged areas for a period of time longer than the travelling time of the incident waves. The results from the two signal processing methodologies applied to the ultrasonic wavefield measured in the honeycomb sandwich composite sample show good correlation with X-ray NDE. They prove that the laser-based nondestructive system is an effective alternative to overcome limitations of conventional NDE technologies.

11:50 AM

Internal Defect Inspection Using Ablation Mode Laser Ultrasonics

---**Sungho Choi** and Sung-Hee Yoon, Department of Mechanical Convergence Engineering, Hanyang University, 222 Wangsimni-ro, Seoungdong-gu, Seoul 133-791, Korea; Kyung-Young Jhang, School of Mechanical Engineering, Hanyang University, 222 Wangsimni-ro, Seoungdong-gu, Seoul 133-791, Korea

---The laser ultrasonics technique was widely studied in the field of the nondestructive evaluation (NDE) to evaluate material features or to detect defects. This technique provides a number of advantages such as non-contact generation and detection of ultrasound without couplants, the ability to operate on curved or rough surfaces, and an increase in scanning speed. In this study, we have investigated the internal defect inspection using ablation mode laser ultrasonics by simulation and experimental tests. The internal defects were made on the steel specimen with various depth positions artificially. In the experiments, a Nd:YAG pulsed laser with a wavelength of 1064 nm and a pulse duration of 5 ns was used to excite the ablation mode laser ultrasonics, and two wave mixing (TWM) interferometer was employed to receive the laser ultrasonics. From both the simulation and experiment, B-scan image was obtained. The results showed that the ablation mode laser ultrasonics is very effective for the internal defect detection.---This research was supported by Nuclear Power Research and Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NRF-2013M2A2A9043241).

Session 26

SESSION 26
COMPOSITES II
Mahmood Haq and Gerges Dib, Co-Chairpersons
Pines-Willows

8:30 AM **Study of the Effect of Increasing Fatigue Damage on the Ultrasonic Coda Wave in Composites**
---**Richard A. Livings**, Vinay Dayal, and Dan J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011

8:50 AM **Elastic Constants Determination and Ultrasonic Propagation Characteristics Analysis of CFRP Composites**
---**Zhong-bing Luo**, Huan-qing Cao, and Li Lin, NDT&E Laboratory, School of Materials Science & Engineering, Dalian University of Technology, Dalian 116085, China

9:10 AM **A Comparative Evaluation of Piezoelectric Sensors for Acoustic Emission-Based Impact Location Estimation and Damage Classification in Composite Structures**
---**Bibhisha Uprety**, Sungwon Kim, and Daniel O. Adams, Department of Mechanical Engineering, University of Utah, Salt Lake City, UT 84112-9208; V. John Mathews, Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112

9:30 AM **Detection of Disbonds in Foam Composite Assemblies Using Flexural Waves and Shearography**
---**Benjamin Lamboul**, Olivier Giraudo, and Daniel Osmont, Onera - The French Aerospace Lab, F92322 Châtillon, France

9:50 AM **Simulation Based Study of Wave Interaction with Multilayer Delamination Damage**
---**Cara A. C. Leckey**, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, Hampton, VA 23681; Jeffrey P. Seebo, Analytical Mechanics Associates, Inc., Hampton, VA 23681

10:10 AM ***Break***

10:30 AM **Model-Based Damage Evaluation of Layered CFPR Structures**
---**R. Muñoz**, N. Bochud, G. Rus, L. Peralta, J. Melchor, J. Chiachio, M. Chiachio, and L. J. Bond[1], NDE Lab, Structural Mechanics Department, University of Granada, Spain; [1]Center for NDE, Iowa State University, Ames, IA 50011

10:50 AM **Numerical Simulation and Experimental Validation of Lamb Wave Propagation Behavior in Composite Plates**
---**Sungwon Kim**, Bibhisha Uprety, and Daniel O. Adams, The University of Utah, Department of Mechanical Engineering, Salt Lake City, UT 84108; V. John Mathews, The University of Utah, Department of Electrical & Computer Engineering, Salt Lake City, UT 84108

11:10 AM **The Depth Limits of Eddy Current Testing for Defects: A Computational Investigation**
---**Samuel Ratnajeevan H. Hoole**, Victor U. Karthik, and Sivamayam Sivasuthan, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, Michigan 48824

11:30 AM **An Eddy-Current Model for Three-Dimensional Nondestructive Evaluation of Advanced Composites**
---**Harold A. Sabbagh**, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC PO Box 7706, Bloomington, IN 47407-7706

11:50 AM ***Session Ends***

12:10 PM ***Lunch***

8:30 AM

Study of the Effect of Increasing Fatigue Damage on the Ultrasonic Coda Wave in Composites

---**Richard A. Livings**, Vinay Dayal, and Dan J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011

---Coda waves are the late arriving portion of bulk or guided waves, and are created by the scattering of the wave due to heterogeneities in the material. Since these waves interact with a region multiple times, the effect of otherwise undetectable changes in material and/or stress state accumulates and becomes detectable. This work examines the feasibility of detecting incipient fatigue damage in CFRP samples by correlating changes in the coda wave velocity, frequency, and phase. Specimens are subjected to low cycle fatigue in a four-point bend set-up. Ultrasonic measurements are taken parallel and perpendicular to the direction of loading, and are taken periodically during the fatiguing process after removing all loads. Coda wave variance is presented for composite samples with sub-critical fatigue damage.

8:50 AM

Elastic Constants Determination and Ultrasonic Propagation Characteristics Analysis of CFRP Composites

---**Zhong-bing Luo**, Huan-qing Cao, and Li Lin, NDT&E Laboratory, School of Materials Science & Engineering, Dalian University of Technology, Dalian 116085, China

---Carbon fiber reinforced plastic (CFRP) composites have been widely applied in aerospace industry in recent years due to the excellent mechanical and material properties. Complex structures and geometries are quite often enquartered in stiffener, ribs, stringers and so on. Since the equivalent stress is mainly concentrated in and around the curved parts, defects and damages such as delamination, debonding and fiber breakage introduced during manufacture might be a great concern to the reliability and ultrasonic nondestructive testing. However, the intrinsic elastic anisotropy of uniaxial laminate has significant implications for the propagation of ultrasonic. So in this study, the elastic and ultrasonic propagation properties of CFRP plate were investigated. A unidirectional CFRP plate was examined with the water immersion ultrasonic technique. The stiffness values were derived in virtue of inversion analysis. Moreover, the ultrasonic velocity, attenuation and frequency domain characteristics of the unidirectional and multi-layered samples were both determined. Based on the results above, a physical model was set up and the propagation behavior of ultrasonic wave was studied. The experimental and calculated results were comprehensively discussed.

9:10 AM

A Comparative Evaluation of Piezoelectric Sensors for Acoustic Emission-Based Impact Location Estimation and Damage Classification in Composite Structures
---**Bibhisha Uprety**, Sungwon Kim, and Daniel O. Adams, Department of Mechanical Engineering, University of Utah, Salt Lake City, UT 84112-9208; V. John Mathews, Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112

---Acoustic Emission (AE) based Structural Health Monitoring (SHM) is of great interest for detecting impact damage in composite structures. Within the aerospace industry the need to detect and locate these events, even when damage is not visible to the eye is important both from the maintenance and design perspectives. In some cases, SHM systems may allow the design of composite structures to damage tolerance levels based on barely detectable rather than barely visible damage criteria. Such a change is expected to permit a significant mitigation of excess conservatism and substantial reductions of material and manufacturing costs. Additionally, maintenance cost may also be significantly reduced since inspection of the structure may be reduced to regions or parts identified by the SHM system. In this paper, several commercially available piezoelectric sensors are evaluated for usage in an AE-based SHM system. Of particular interest was comparing the acoustic response of the candidate piezoelectric sensors for impact location estimations as well as damage classification resulting from the impact in fiber-reinforced composite structures. Four different types of AE sensors were selected for investigation. Initial experiments involved both active testing to evaluate directionally-dependent acoustic response and passive testing using steel-ball drops. Follow-on low-velocity instrumented impacts were also performed using quasi-isotropic carbon/epoxy panels to initiate specific damage types. A series of increasing impact energies and varying support conditions were used to produce different severities and types of damage in composite plates. The sensor responses produced by these impacts provided time-of-arrival and velocity measurements of initial symmetric (So) and asymmetric (Ao) wave modes, which are useful for assessing the impact location estimation algorithm. Subsequent damage determinations were performed using both ultrasonic C-scan (delaminations) and pyrolysis/deply (fiber damage). Collectively, these results are used to assess the performance of the candidate AE sensors for use in both impact location estimation and impact damage classification in composite structures.---This work is supported in part by the National Aeronautics and Space Administration (Award No. NNM13AA12G) and the Air Force Office of Scientific Research (Award No. FA95501210291).

9:30 AM

Detection of Disbonds in Foam Composite Assemblies Using Flexural Waves and Shearography

---**Benjamin Lamboul**, Olivier Giraudo, and Daniel Osmont, Onera - The French Aerospace Lab, F92322 Châtillon, France

---Composite foam assemblies are used in the aerospace industry for the design of lightweight structures. For some applications, a thermal insulation function is also ensured by these assemblies in addition to their structural role. NDT is required during the manufacturing process to ensure that no significant disbond is present between the foam and the skin material. As interfaces with air (disbonded interfaces) provide little contrast with foam (correctly bonded) interfaces, standard techniques like thermography or ultrasonic C-scans seldom prove effective for the inspection of such assemblies. Over the past years, Onera has developed an original dynamic shearography technique for this type of application. The method used relies on the contrast in flexural behavior between sound regions of the assembly and disbonded areas. A flexural wave is excited in the structure and out-of-plane displacements are imaged by shearography, using a stroboscopic acquisition principle: the field under investigation is illuminated synchronously with the continuous wave signal by an Nd-YAG Laser. The relative phase to the excitation signal can be automatically varied to acquire a set of images over a full period. A final accumulated energy map (the sum of squared shearographic images obtained for different relative phases) is computed to enhance defects signatures. This paper reviews the principle of the technique and illustrates its application to circular calibrated disbond defects in a foam core sandwich plate with glass-fiber skins. The role of local flexural resonance in the obtention of clear defect signatures is investigated and highlighted with the help of separate Laser Doppler vibrometry scans. Finally, the paper discusses the attainable detection performance with the method in terms of defect radius-to-wavelength ratio for the chosen application example.

9:50 AM

Simulation Based Study of Wave Interaction with Multilayer Delamination Damage
---**Cara A. C. Leckey**, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, Hampton, VA 23681; Jeffrey P. Seebo, Analytical Mechanics Associates, Inc., Hampton, VA 23681

---Nondestructive Evaluation (NDE) and Structural Health Monitoring (SHM) simulation tools capable of modeling three-dimensional (3D) realistic energy-damage interactions are needed for aerospace composites. Current practice in NDE/SHM simulation for composites commonly involves over-simplification of the material parameters and/or damage geometry/type, and/or a simplified two-dimensional (2D) approach. The unique damage types that occur in composite materials (i.e., delamination, microcracking, etc.) develop as 3D complex geometry features. Moving the state-of-art towards rapid, realistic NDE/SHM simulations is necessary in order to enable simulation based inspection predictability, model-assisted probability of detection, and SHM validation for composites. Such tools would also allow for more cost-effective and timely development of optimized inspection and damage characterization methods for composite components. This paper discusses the application of 3D custom ultrasonic simulation tools to study wave interaction with composite damage. In particular, simulation based studies of ultrasonic guided wave behavior and energy trapping due to multilayer delamination damage will be discussed. The paper will also describe recent advancements in porting the custom ultrasonic simulation code from use on large computing cluster resources to less costly computational resources; while also accomplishing significant increases in computation speed.

10:30 AM

Model-Based Damage Evaluation of Layered CFPR Structures

---**R. Muñoz**, N. Bochud, G. Rus, L. Peralta, J. Melchor, J. Chiachio, M. Chiachio, and L. J. Bond[1], NDE Lab, Structural Mechanics Department, University of Granada, Spain; [1]Center for NDE, Iowa State University, Ames, IA 50011

---An ultrasonic evaluation technique for damage quantification and location is presented for CFRP layered structures, based in a model-based estimation procedure that combines experimental and simulation of ultrasound damage-propagation interaction. It has been tested in an underwater through transmission experiment, where a scan has been performed on a previously damaged specimen. Most ultrasonic techniques in industrial practice consider one or a few features of the received signals, namely, time of flight, echo amplitude, attenuation, frequency contents, and so forth. In this case, once signals are captured, and algorithm is used to reconstruct the unknown damage parameters by means of modeling procedures. The CFPR structure, a [0/90]4s lay-up, has been modelled as a 32 layered material. Each layer at each location of the scan presents its own value for the selected material damage parameters, such as Young Modulus reduction, attenuation or first order nonlinear classical parameter β. Damage is expressed in changes in the material parameters. In a first experience, only Young modulus has been monitored and, in a second one, β parameter was incorporated to show the early capacity to detect damage. The aforementioned physical models are solved by means of the Transfer Matrix formalism [1], both linear and nonlinear, to compute the simulated signals. Each set of selected material parameters would yield to a different computed signal, since the model depends on them. The strategy is to obtain the suitable set of parameters of the layers, so that the captured signals are simulated with a minimal error [2], using a Genetic Algorithm. Once the signal is reproduced, changes in its set of layer parameters are observed. Processing all scanned locations, a 3D reconstruction of the specimen's parameters is presented, layer by layer and interface by interface. Damage can be located and quantified in terms of changes of the selected parameter with a measurable extension. In the case of using models with nonlinear parameter β, large variations are detected in low damaged areas compared to non-damaged areas, while Young Moduli are unaltered maintained at this damage levels. This evaluation procedure, based on physical models, can be easily adapted to solve the inverse problem in a probabilistic way [3] being a suitable input for prognosis tools, due to their statistical nature.**---**The authors acknowledge the Spanish Ministerio de Economía y Competitividad for project DPI2010-17065, and Junta de Andalucía for projects P11-CTS-8089 and GGI3000IDIB, as well as the European Union for the 'Programa Operativo FEDER de Andalucía 2007-2013'. The authors are also grateful to the END Lab team for their support.

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10:50 AM

Numerical Simulation and Experimental Validation of Lamb Wave Propagation Behavior in Composite Plates
---**Sungwon Kim**, Bibhisha Uprety, and Daniel O. Adams, The University of Utah, Department of Mechanical Engineering, Salt Lake City, UT 84108; V. John Mathews, The University of Utah, Department of Electrical & Computer Engineering, Salt Lake City, UT 84108

---Structural Health Monitoring (SHM) based on Acoustic Emission (AE) is dependent on both the sensors to detect an impact event as well as an algorithm to determine the impact location. The propagation of the Lamb waves produced by an impact event in thin composite plates is affected by several unique aspects of a layered, fiber-reinforced composite plate, including material anisotropy, ply orientations, and geometric discontinuities within the plate. The development of accurate numerical models of Lamb wave propagation has important benefits towards the development of AE-based SHM systems for impact location estimation. Currently, many impact location algorithms use the time of arrival or velocities of Lamb waves. Therefore the numerical prediction of characteristic wave velocities is of great interest. Additionally, the propagation of the initial symmetric (So) and asymmetric (Ao) wave modes is important, as these wave modes are to be used for time of arrival estimation. In this investigation, two- and three- dimensional finite element analyses were performed using the commercial finite element code ANSYS to investigate aspects of Lamb wave propagation in composite plates. A comparative evaluation of several 2D and 3D modeling approaches was performed, with emphasis placed on the propagation and velocity of both the So and Ao wave modes. Results from numerical simulations were compared to experimental results obtained from active AE testing performed with an idealized impact signal. Of particular interest is the arriving So and Ao wave modes versus wave propagation direction in quasi-isotropic and generally orthotropic carbon/epoxy composite plates. Numerical and experimental results suggest that although a quasi-isotropic composite plate may have the same effective elastic modulus in all in-plane directions, the Lamb wave velocity will have some directional dependence. Further numerical analyses were performed to investigate the Lamb wave propagation associated with simple geometric discontinuities including cut-outs, build-ups and internal ply delaminations. Key results obtained include a recommended finite element analysis methodology and the associated agreement between predicted and measured Lamb wave propagation in a quasi-isotropic carbon/epoxy composite plate.---
This work is supported in part by the National Aeronautics and Space Administration (Award No. NNM13AA12G) and the Air Force Office of Scientific Research (Award No. FA95501210291).

11:10 AM

The Depth Limits of Eddy Current Testing for Defects: A Computational Investigation

---**Samuel Ratnajeevan H. Hoole**, Victor U. Karthik, and Sivamayam Sivasuthan, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, Michigan 48824

---Eddy current testing is a widely accepted, cheap and portable method for the detection of cracks and other defects in conductive materials. While eddy current testing (ECT) is a favorite with engineers for surface defect identification through nondestructive evaluation (NDE), for more deeply embedded defects the literature is vague, with statements such as low frequency testing being able to distinguish "all the different levels" of corrosion. Even as some researchers have established that eddy current testing can identify corrosion to depths down to 15 mm (0.6 in), others working with pulsed eddy currents which have low frequency components penetrating more deeply into the object under test, have reported identifying defects at a 1.5 in depth and more. However, the reality is that when a defect is perpendicular to the surface of a plate, it does not interrupt the flow of eddy currents thereby making itself difficult to be identified. On the other hand if the defect is parallel to the surface, the defect will be detectable through the interruption of the eddies. Moreover, if the axis of the external exciting ECT coil is parallel to the surface, our considerations need to be entirely different. This study through a series of finite element analyses of parameterized geometries of a single defect, seeks to identify the limits of eddy current testing in NDE. It is confined to steel and composite plates for army ground vehicle armor. A relationship between the depth of a detectable defect, the frequency of excitation and the geometric parameters is identified to help engineers choose whether or not to use ECT.

11:30 AM

An Eddy-Current Model for Three-Dimensional Nondestructive Evaluation of Advanced Composites

---**Harold A. Sabbagh**, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

---We have developed a rigorous electromagnetic model and an inversion algorithm for the three-dimensional NDE of advanced composite materials. This approach extends Victor Technologies' work in eddy-current NDE of conventional metals, and allows one to determine in localized regions the fiber-resin ratio in graphite-epoxy, and to determine those anomalies, e.g., delaminations, broken fibers, moisture content, etc., that can be reconstructed by our inversion method. In developing the model, we apply rigorous electromagnetic theory to determine a Green's function for a slab of anisotropic composite material, and then determine the integral relations for the forward and inverse problems using the Green's function. We will give examples of the solution of forward and inverse problems using these algorithms.

Session 27

SESSION 27
MODELLING
Pierre Calmon, Chairperson
Salmon-Snake

8:30 AM **The Validity of the 3D Elastic Kirchhoff Approximation for Rough Crack Scattering Signals Using a Finite Element Approach**
---**Fan Shi**, Wonjae Choi, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Elizabeth Skelton and Richard Craster, Imperial College, Mathematics, London, United Kingdom

8:50 AM **Modelling NDE Pulse-Echo Inspection of Misorientated Planar Rough Defects Using a Fully Elastic Finite Element Method**
---**James Pettit** and Michael Lowe, Imperial College, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom; Anthony Walker, Rolls-Royce Nuclear, Derby, United Kingdom

9:10 AM **Weld Quality Inspection Using Laser Generated Lamb Waves: Finite Element Study**
---**Lei Yang** and I. Charles Ume, Georgia Institute of Technology, G.W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332-0405

9:30 AM **High Order Nystrom Method for Acoustic Scattering**
---Kun Chen, Siming Yang, and **Jiming Song**, Iowa State University, Dept. of Electrical and Computer Engineering, Ames, IA 50011; Ronald Roberts, Iowa State University, Dept. of Aerospace Engineering and Center for NDE, Ames, IA 50011

9:50 AM **Prediction of the Ultrasonic Response of Crack-Like Defects Using a Mixed Kirchhoff-GTD Model**
---**Vincent Dorval**, Michel Darmon, and Sylvain Chatillon, CEA-LIST, Gif-sur-Yvette, France; Larissa Fradkin, Sound Mathematics Ltd., Cambridge, United Kingdom

10:10 AM ***Break***

10:30 AM **Recent Modelling Advances for Ultrasonic TOFD Inspections**
---Michel Darmon, Adrien Ferrand, Vincent Dorval, and **Sylvain Chatillon**, CEA, LIST, Department Imaging and Simulation for NDT, 91191 Gif-sur-Yvette, France

10:50 AM **3D Simulation of Focusing Ultrasound in Multi-Layered Tissues for Improvement of HIFU**
---**Young-In Hwang**, Jae-Hyun Bae, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Suwon, Korea; Ki-Bok Kim, Korea Research Institute of Standards and Science, Daejeon, South Korea

11:10 AM **Inspection of Spar-Core Bond in Helicopter Rotor Blades Using Finite Element Analysis**
---**Sunil Kishore Chakrapani**[1], Daniel Barnard[2], and Vinay Dayal[2], [1]Department of Aerospace Engineering & CNDE Iowa State University, Ames IA 50010; [2]CNDE, Iowa State University, Ames, IA 50011

11:30 AM **Finite Element Analysis of the Non-linear Coupling Effect of Coupling Materials in Ultrasound Infrared Imaging**
---**Yuyang Song** and Xiaoyan Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48104

11:50 AM **A Thermographic Approach for Surface Crack Depth Evaluation Through 3D Finite Element Modeling**
---**Mohammed Basheer Chalil**, Parag Ravindran, and Krishnana Balasubramaniam, Indian Institute of Technology, Centre for Non Desstructive evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu 600036, India

12:10 PM ***Lunch***

8:30 AM

The Validity of the 3D Elastic Kirchhoff Approximation for Rough Crack Scattering Signals Using a Finite Element Approach

---**Fan Shi**, Wonjae Choi, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Elizabeth Skelton and Richard Craster, Imperial College, Mathematics, London, United Kingdom

---The Kirchhoff approximation to calculate the elastic wave scattering from 2D rough cracks is examined by a comparison with a 3D finite element (FE) approach. This approach couples a time domain finite element solver and a hybrid method to compute the scattering signals from rough cracks. 2D random rough surface with Gaussian profiles are used in this paper to study the validity of the Kirchhoff approximation. Simulations are run as a function of incident/scattering angle, roughness, correlation length, and band width of the input signal. Both the shape and the peak amplitude of the received signal are compared using the two different numerical approaches. Certain restricted ranges for the Kirchhoff approximation are found through the comparison with the FE method.

8:50 AM

Modelling NDE Pulse-Echo Inspection of Misorientated Planar Rough Defects Using a Fully Elastic Finite Element Method

---**James Pettit** and Michael Lowe, Imperial College, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom; Anthony Walker, Rolls-Royce Nuclear, Derby, United Kingdom

---Pulse-echo ultrasonic NDE techniques are regularly used to inspect large pressure vessel forgings. Such inspections aim to size and characterize potential defects that may have formed during the forging process. Typically these defects possess varying degrees of orientation and surface roughness which can greatly affect ultrasonic wave scattering behavior. Ultrasonic modelling techniques can provide insight into defect response and therefore aid in characterization. However, analytical approaches to solving these scattering problems can become inaccurate, especially when applied to increasingly complex defect geometries. Here, a fully elastic Finite Element (FE) method is used to simulate pulse-echo inspections of embedded planar defects. The FE model comprises a significantly reduced spatial domain allowing for a Monte-Carlo based approach to consider multiple realizations of defect orientation and surface roughness. The results confirm that defects aligned perpendicular to the path of beam propagation attenuate ultrasonic signals according to the level of surface roughness. However, for defects orientated away from this plane, surface roughness can increases the magnitude of the scattered component propagating back along the path of the incident beam. This study therefore highlights instances where defect roughness increases the magnitude of ultrasonic scattered signals, as opposed to attenuation which is more often assumed.

9:10 AM

Weld Quality Inspection Using Laser Generated Lamb Waves: Finite Element Study

---**Lei Yang** and I. Charles Ume, Georgia Institute of Technology, G.W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332-0405

---Among various non-destructive testing (NDT) techniques for weld quality inspection, laser/EMAT ultrasonic (LEU) technique is attracting a lot of interests because of its none-contact characteristics. Effective Time of Flight (TOF) based signal interpretation methods have been developed for weld inspection in thick structures where the laser generated ultrasounds are primarily bulk waves. However, in thin structures, Lamb waves are prominent in the laser generated ultrasounds. The broadband nature of laser excitation and generated Lamb waves of multiple modes make the received signals very complicated. The TOF analysis used for bulk waves is not suitable for Lamb waves. In order to extend the use of LEU technique to inspect thin structures, it is essential to understand how the laser generated Lamb waves interact with welds. In this work, the laser generated Lamb waves are characterized experimentally first to identify the most prominent modes in the received signals. A simple but effective finite element analysis (FEA) model is developed to simulate the propagations of a single mode narrow band (SMNB) Lamb wave in an isotropic thin plate. For those prominent Lamb wave modes identified, their scattering at weld joint are modeled with the FEA model which was previously developed. Reflection, transmission and mode conversion are observed and further parametric study shows that they can be used to predict the weld quality.

9:30 AM

High Order Nystrom Method for Acoustic Scattering

---Kun Chen, Siming Yang, and **Jiming Song**, Iowa State University, Dept. of Electrical and Computer Engineering, Ames, IA 50011; Ronald Roberts, Iowa State University, Dept. of Aerospace Engineering and Center for NDE, Ames, IA 50011

---While high frequency approximation methods are widely used to solve flaw scattering in ultrasonic nondestructive evaluation, full wave approaches based on integral equations have great potentials due to their high accuracy. In this work, boundary integral equations for acoustic wave scattering are solved using high order Nystrom method. Compared with boundary elements method, it features of the coincidence of the samples for interpolation basis and quadrature, which makes the far-field interaction free from numerical integration. The singular integral is dealt with using the Duffy transformation, while efficient singularity subtraction techniques are employed to evaluate the near singular integrals. This approach has the ease to go high order so highly accurate results can be obtain with fewer unknowns and faster convergence, and it is also amenable to incorporate fast algorithms like the multi-level fast multipole algorithm. The convergence of the approach for different orders of elements and interpolation basis functions is investigated. This approach is validated by comparing with analytic and experimental results.

9:50 AM

Prediction of the Ultrasonic Response of Crack-Like Defects Using a Mixed Kirchhoff-GTD Model

---**Vincent Dorval**, Michel Darmon, and Sylvain Chatillon, CEA-LIST, Gif-sur-Yvette, France; Larissa Fradkin, Sound Mathematics Ltd., Cambridge, United Kingdom

---The modeling of ultrasonic Non Destructive Evaluation often plays an important part in the assessment of detection capabilities or as a help to interpret experiments. The ultrasonic modeling tool of the CIVA platform uses semi-analytical approximations for fast computations. Kirchhoff and GTD are two classical approximations for the modeling of echoes from planar defects such as cracks, and they aim at taking into account two different types of phenomena. The Kirchhoff approximation is mainly suitable to predict specular reflections from the flaw surface, whereas GTD is dedicated to the modeling of edge scattering. As a consequence, these two approximations have distinct and complementary validity domains. Choosing between them requires expertise and is problematic in ambiguous cases. The Physical Theory of Diffraction (PTD) was developed based on both Kirchhoff and GTD in order to combine their advantages and overcome their limitations. The PTD model and its implementation for NDE simulation are presented in this communication. Examples that validate this approach and illustrate its advantages are reported.

10:30 AM

Recent Modelling Advances for Ultrasonic TOFD Inspections

---Michel Darmon, Adrien Ferrand, Vincent Dorval, and **Sylvain Chatillon**, CEA, LIST, Department Imaging and Simulation for NDT, 91191 Gif-sur-Yvette, France

---The ultrasonic TOFD (Time of Flight Diffraction) Technique is commonly used to detect and characterize disoriented cracks using their edge diffraction echoes. An overview of the recent advances implemented in the CIVA software platform and devoted to TOFD simulation is presented. First, the implementation of 3D GTD (Geometrical Theory of Diffraction) coefficients allows predicting diffraction echoes from complex flaws in full 3D configurations. Other dedicated developments have been added to simulate lateral waves in 3D on planar entry surfaces and in 2D on irregular surfaces by a ray approach. Calibration echoes from SDHs and backwall echoes can also been modelled. Some examples of numerical validation of these models are presented. In addition, experimental validations have been performed both on planar blocks containing calibration holes and various notches and on a specimen with an irregular entry surface and allow drawing conclusions on the validity of all the developed models.

10:50 AM

3D Simulation of Focusing Ultrasound in Multi-Layered Tissues for Improvement of HIFU

---**Young-In Hwang**, Jae-Hyun Bae, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Suwon, Korea; Ki-Bok Kim, Korea Research Institute of Standards and Science, Daejeon, South Korea

---High-Intensity Focused Ultrasound (HIFU) has been widely used in clinical practice as a non-invasive treatment for diseased or damaged tissue through ablation by focusing high intensity ultrasound energy to a small region of target tissue in human body. So, the main advantage of this method is that it can be performed without an incision. So, HIFU can be non-invasively applied to some cancer treatments. For example, uterine fibroids, prostate cancer, hepatic, renal, breast and pancreatic tumors. For focusing HIFU energy to a target such as a tumor in complex human body, precise ray tracing method or techniques is needed. However, from skin to the object, human body is complex with tissue heterogeneity. Therefore, by calculation HIFU beam fields in the, ultrasonic simulation of HIFU with biological virtualization can support the design and operation of HIFU system. With the Simulation a biological virtualization to each case of tumor for the HIFU simulation, the position of focal point can be described and the pressure and temperature rise can be measured on each part of human body around target. By this information, time-delay values from each transducer in phase array can be calculated and the appropriate geometric shape of HIFU transducer can be set. Thus, in this study, the simulation was performed according to the parameter of HIFU sensor and applied in case of the part surrounded by bones.

11:10 AM

Inspection of Spar-Core Bond in Helicopter Rotor Blades Using Finite Element Analysis

---**Sunil Kishore Chakrapani**[1], Daniel Barnard[2], Vinay Dayal[2], [1]Department of Aerospace Engineering & Center for NDE, Iowa State University, Ames IA 50011; [2]Center for NDE, Iowa State University, Ames, IA 50011

---This work focuses on inspection of spar-core bond of a helicopter rotor blade using finite element analysis. Structures which have high density, high stiffness cores can be very difficult to inspect due to various mode conversions. FEM was used to capture these mode conversions effectively. The structure consists of a thin spar section followed by a spar-core half space and another thin spar section. A Lamb wave excited in the spar section can mode convert into a Rayleigh wave in the spar-core section due to the coupling of the core material. This in turn mode converts back into a Lamb wave upon interacting with the next spar section. Damage was modeled in the form of a notch (to simulate a core crack) and delamination between core and spar sections.

11:30 AM

Finite Element Analysis of the Non-linear Coupling Effect of Coupling Materials in Ultrasound Infrared Imaging

---**Yuyang Song** and Xiaoyan Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48104

---Sonic Infrared Imaging is a novel technique which implements the concept of combining infrared (IR) sensing and imaging with pulsed (typically a fraction of a second) sonic/ultrasonic excitation to detect the frictional heating in cracks from target. It was demonstrated that coupling materials, a thin material engaged between an ultrasound transducer and a sample, has strong non-linear effect in crack detection. We had showed some results previously that different coupling materials have different effect to the vibration waveforms and heating at the edge crack of an Aluminum bar sample. In this paper, we will present finite element analysis data on these coupling materials. A comprehensive comparison between experimental and FEA results using the vibration waveforms and IR images on aluminum bar sample will be presented.

11:50 AM

A Thermographic Approach for Surface Crack Depth Evaluation Through 3D Finite Element Modeling

---**Mohammed Basheer Chalil**, Parag Ravindran, and Krishnana Balasubramaniam, Indian Institute of Technology, Centre for Non Desstructive evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu 600036, India

---Pulsed Laser Thermography is novel technique to find fatigue crack in metals which grows predominantly perpendicular to the surface that can't be detected by conventional thermography. The detection of these crack is an important task to prevent structural failure as the wide spread use of low ductility, high performance steel in lightweight constructions. It uses a powerful laser beam which produces a highly localized heating spot from which heat diffuses radially. A pulsed laser source is used for producing a heat spot on the sample near to the surface breaking crack which will delay the lateral heat flow and this disturbance is observed by an IR camera which will reveal the crack. The hot spot is then scanned over a region to map the crack. This allows for a remote imaging of crack morphology, even in elevated temperatures. The present study involves 3D finite element (FE) simulation using COMSOL as a tool to simulate the thermal flow from the laser heated spot in the proximity of a crack. The modeling helped us to develop a relationship between the surface temperature across the crack and depth of crack that will help to read the depth of crack indirectly by the IR camera and hence will reduce the time of inspection. It also helped to understand the various parameters affecting the thermal images of laser heated spots which utilized to develop a strategy for extracting the details of the crack.

Session 28

SESSION 28 – POSTERS
ULTRASONIC CHARACTERIZATION, ULTRASONICS, MATERIALS CHARACTERIZATION, SIGNAL PROCESSING, ADVANCED MATERIALS, COMPOSITES
Hawk

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Ultrasonic Characterization

High-Selectivity Imaging of Closed Fatigue Crack with Coarse Grain by Load Difference Phased Array with Global Preheating and Local Cooling
---**Koji Takahashi**, Kouki Ohmachi, Kentaro Jinno, Yoshikazu Ohara, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

Electrical Conductivity and Magnetic Permeability Measurement of Case Hardened Steel
---**Yong Tian**, The Timken Company, WHQ-04, PO Box 6930, Canton, OH 44706-0930

Characterization of Microstructure in 9 Cr- 1 Mo Alloy by Ultrasonic Measurements
---**Seung-seok Lee**, Seung-hyun Cho, Dae-chul Seo, and Choon-soo Park, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea; Weon-bae Hahn, Chong-seung Yoon, Hanyang University, Division of Materials Sciences and Engineering

Ultrasonic Fields and Inspection of Huge Complex Composites
---**Chunguang Xu**, Hongbo Wang, and Dingguo Xiao, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, China

Ultrasonics

Automatic Ultrasonic Inspection System for Wear Determination in Calandria Tubes of Embalse Nuclear Power Plant
---**Pablo Katchadjian**, Carlos A. Desimone, and Alejandro D. Garcia, Comision Nacional de Energia Atomica, Departamento de Ensayos No Destructivos y Estructurales, Buenos Aires, Argentina; Carlos Antonaccio, Fernando Schroeter, and Hector Molina, Nucleoelectrica Argentina S.A., Departamento de Ingenieria Mecanica, Buenos Aires, Argentina

Monitoring System for the Quality Assessment in Additive Manufacturing
---**Volker Carl**, Carl Messtechnik, Dinslaken, Germany

The Application of High-Speed GPU-Based Finite Element Simulations to NDT
---**Peter Huthwaite**, Anton Van Pamel, Fan Shi, and Michael J. S. Lowe, Imperial College London, Department of Mechanical Engineering, London, United Kingdom

Adaptive Ultrasonic Imaging with the Total Focusing Method for Inspection of Complex Components Immersed in Water
---**Léonard Le Jeune** and Sébastien Robert, CEA, LIST, Gif-sur-Yvette, F-91191, France; Philippe Dumas and Arnaud Membre, IMASONIC, Voray-sur-l'Ognon, F-70190, France; Claire Prada, Institut Langevin, 1 rue Jussieu, 75238 Paris Cedex 05, France

Ultrasonic Inspection to Quantify Failure Pathologies of Crimped Electrical Connections
---**K. Elliott Cramer**, Daniel F. Perey, and William T. Yost, National Aeronautics and Space Administration, Langley Research Center, 3B E. Taylor Street, Hampton, VA 23681

Characterization of Carbonation, Shrinkage, and Creep in Concrete Using Nonlinear Rayleigh Waves
---**Gun Kim**[1], Jin Yeon Kim[1], Kimberly E. Kurtis[1], and Laurence J. Jacobs[1,2], [1]Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355; [2]GW Woodruff School of Mechanical Engineering, Atlanta, GA 30332

Evaluation of Delayed Ettringite Formation Using Nonlinear Impact Resonance Spectroscopy Method
---**Mohammad M. N. Rashidi**, Alvaro Paul, and Kimberly E. Kurtis, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; Jin-Yeon Kim and Laurence J. Jacobs, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332

Near Field Effects and Estimation of Poisson's Ratio in Impact-Echo Thickness Testing
---**Oskar Baggens** and Nils Rydén, Division of Engineering Geology, Lund University, S-221 00 Lund, Sweden

Automated Flaw Detection for NDE Images
---Ye Tian, Amgen Inc., Thousand Oaks, CA 91320; Ranjan Maitra, Department of Statistics and Statistical Laboratory, Iowa State University, Ames, IA 50011; **William Q. Meeker**, Department of Statistics and the Center for NDE, Iowa State University, Ames, IA 50011; Stephen D. Holland, Department of Aerospace Engineering and Center for NDE, Iowa State University, Ames, IA 50010

Materials Characterization

Transient Potential Drop Field Measurements Using a Four Point Probe
---**Yuan Ji and John R. Bowler**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Instrument for Fast Alternating Current Potential Drop Measurement
---**Yuan Ji**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Nondestructive Evaluation of Stress Corrosion Cracking in Welded 304 Stainless Steel Using Nonlinear Rayleigh Waves
---**Florian Morlock**, Katie Matlack, Jin-Yeon Kim, James J. Wall, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30318; Preet Singh, Georgia Institute of Technology, Institute of Paper Science and Technology, Atlanta, GA 30318

Using Nonlinear Ultrasonic Measurements to Detect and Assess the Stage of Thermal Damage in 2507 Super Duplex Stainless Steel and 9–12 Cr FM Steel
---**Daniel Marino**, Jin-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30318; Alberto Ruiz, Instituto de Investigaciones Metalurgicas, UMSNH, Morelia, Mexico; Young-Sang Joo, Korea Atomic Energy Research Institute, Daejon, Korea

Application of the Wavelet Transform to Acoustic Emission Signals Processing to Distinguish Corrosion Type
---**Rodrigo S. da Silva**, João M. A. Rebello, and Gabriela R. Pereira, Laboratory of Non-Destructive Testing, Corrosion and Welding, Department of Metallurgical and Materials Engineering, Federal University of Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil; Sérgio D. Soares, PETROBRAS Research and Development Center, Rio de Janeiro, Rio de Janeiro, Brazil

Relation Between Low-Frequency Components in Ultrasonic Waves Propagating Through Contacting Solids and Acoustic Emission Waves
---**Hirotaka Tanaka**, Yuji Kato, and Toshihiko Sugiura, Keio University, Department of Mechanical Engineering, Yokohama, Kanagawa, Japan

Nonlinear Parameter Calculation in Consideration of the Second Harmonic Frequency Component of Incident Ultrasonic Waves
---**Seung Hyun Cho**, Choonsu Park, and Dea Cheol Seo, Korea Research Institute of Standards and Science, Yuseong-gu, Daejon, South Korea

Characterization of 3D Rapid Prototyped Polymeric Material by Ultrasonic Methods
---**Richard A. Livings**, Vinay Dayal, and Dan J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011

Signal Processing

Clutter Noise Reduction for Phased Array Imaging Using Spatial-Frequency Polarity Coherence in Ultrasonic NDE
---**Rui Gongzhang**, Anthony Gachagan, and Bo Xiao, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom

Speckle Suppression Using Adaptive Frequency Compounding in Ultrasound Nondestructive Evaluation of Coarse-Grained Material
---**Bo Xiao**, Rui Gongzhang, Timothy Lardner, Richard L. O'Leary, and Anthony Gachagan, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, United Kingdom

Surface Reconstruction Methods with Phased-Arrays for Adaptive Ultrasonic Imaging in Complex Components Immersed in Water
---Sébastien Robert, P. Calmon, L. Le Jeune, and E. Lakovleva, CEA-LIST, Centre de Saclay, 91191 Gif-sur-Yvette, France

Structural Health Monitoring Method Based on the Entropy of an Ultrasonic Sensor Network for a Plate-Like Structure
---**Erick Rojas** and Arturo Baltazar, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional – Unidad Saltillo, 25900, Coah, Mexico

Detection of Structural Damage in Multiwire Cables by Monitoring the Entropy of Continuous Wavelet Transform
---**Flor Ibáñez** and Arturo Baltazar, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Robotics and Advanced Manufacturing Program, Ramos Arizpe, Coahuila, México; Rito Mijarez, Instituto de Investigaciones Eléctricas, Gerencia de Control e Instrumentación, Cuernavaca, Morelos, México; Jorge Aranda, Facultad de Ciencias Físico-Matemáticas. Universidad Michoacana de San Nicolás de Hidalgo. Morelia, Michoacán, México

Influence of Curvature of Wire-Ropes on Guided Wave Propagation
---**Kousuke Kanda** and Toshihiko Sugiura, Keio University Department of Mechanical Engineering, Kohokuku, Kanagawa, 223-8522, Japan

Advanced Materials

Langmuir-Blodgett Bacteriorhodopsin Monolayer Surface CARS Spectroscopy
---S. I. Valyanskii and **E. K. Naimi**, National University of Science and Technology “MISIS”, Leninskiy prosp. 4, 119049, Moscow, Russia

Study of Ultrasonic Characteristics in Single-Layer Carbon Fiber Reinforced Plastic
---**Xianglin Zhan**, Xueqian Tang, Dai Liu, and Tao Liu, College of Aeronautical Automation, Civil Aviation University of China (North Campus, 2898# JinBei Road, Tianjin 300300, China (PRC)

NDE of Transparent Protective Panels
---**Dan Barnard**, Frank Margetan, Chien-Ping Chiou, Aaron Herman, and Brittney Pavel, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Inspection Techniques for Adhesively Bonded Stacked Open Honeycomb Core Composites
---**Clint D. Thomson**, ATK Aerospace Structures Aerospace Structures Division, Inspections Development Group, Clearfield UT 84016; Mohammad Tayeb Ahmed Ghasr, Kuang P. Ying, and Reza Zoughi, Missouri University of Science and Technology, Electrical and Computer Engineering Department Applied Microwave Nondestructive Testing Laboratory, Rolla, MO 65409-0040

Experimental Studies on NRUS Behavior of Impact Damaged Composite Laminates
---**Hyunjo Jeong**, Wonkwang University, Mechanical and Automotive Engineering, Iksan, Jonbuk, Korea; Daniel Barnard, Iowa State University, Center for NDE, Ames, IA 50011

Ultrasonic Impact Damage Assessment in Woven Composite Materials
---Emira Mannai, **Benjamin Lamboul**, and Jean-Michel Roche, Onera - The French Aerospace Lab, F92322, avenue de la Division Leclerc, F923322 Châtillon, France

Composites

Characterization of Fiber Content and Distribution in Natural Fiber-Reinforced Composites by Ultrasonic Techniques
---Inna Seviaryna, Heloisa Gomes Bueno, and Elena Maeva, University of Windsor, Physics Department, Windsor, Ontario, Canada; Jimi Tjong and Birat Singh KC, Ford Motor Company, Powertrain Engineering Research and Development Centre, Windsor, Ontario, Canada (Poster presented by **Mehdi Hajian**)

3:10 PM ***Break***

Ultrasonic Characterization

High-Selectivity Imaging of Closed Fatigue Crack with Coarse Grain by Load Difference Phased Array with Global Preheating and Local Cooling

---**Koji Takahashi**, Kouki Ohmachi, Kentaro Jinno, Yoshikazu Ohara, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---We have developed a closed crack imaging method, subharmonic phased array for crack evaluation (SPACE) [Ohara, et al., APL, 2007]. However, the selectivity of closed cracks is degraded due to linear scatterers such as coarse grains when SPACE uses short-burst input waves. Therefore we have proposed load difference phased array (LDPA) [Ohara, et al., Ultrasonics, 2011] and have verified it with the practical thermal-stress application method, global preheating and local cooling (GPLC) [Ohara, et al., APL, 2013]. However, it has yet to be verified in the specimen with coarse grains. The objective of this study is to verify it in a specimen with a closed crack and coarse grains. In GPLC, the top surface of specimen is locally cooled with a cooling spray after global preheating. This results in a tensile thermal stress by a principle similar to that of a three-point bending test, and thereby, the crack is opened. During this process, the crack is imaged by linear phased array (PA). Subsequently, by subtracting between PA images before and after GPLC, only the closed crack is imaged while canceling linear scatterers such as coarse grains. In this study, to form the closed fatigue crack, a maximum stress intensity factor of 18.6 MPam1/2 was decreased to 8.6 MPam1/2 with the increase in crack depth and a minimum stress intensity factor was 0.6 MPam1/2. First, we imaged the crack with applying a mechanical load by a servohydraulic testing machine. As a result, the crack depth measured in the PA images changed from 7.4 mm to 13.3 mm depending on the load. This shows that the crack is partially closed and the true crack depth was 13.3 mm. After this confirmation, the crack was imaged by PA during applying GPLC. As a result, it was confirmed in PA images that the crack tip was opened by GPLC. However, the multiple coarse grains were also imaged with the intensities similar to those of the crack tip. Thus, to enhance the selectivity, we applied the LDPA to the PA images before and after applying the thermal stress. As a result, only the closed crack was imaged and the linear scatterers such as coarse grains were canceled, and thereby, the crack depth was accurately measured.

Ultrasonic Characterization

Electrical Conductivity and Magnetic Permeability Measurement of Case Hardened Steel

---**Yong Tian**, The Timken Company, WHQ-04, P. O. Box 6930, Canton, OH 44706-0930

---For surface modified steels, hardness and carbon content are closely related to electromagnetic properties. In particular, electrical conductivity and magnetic permeability profiles are commonly needed to the development of model-based characterization techniques for purpose of nondestructive quality control. To obtain accurate profiles of these material properties, three measurement approaches are applied on standard circular-shaped discs cut off from case carburized steels. First, a four-point direct-current potential drop (DCPD) approach is applied to measure electrical conductivity. Second, an alternating current potential drop (ACPD) approach is used to measure both electrical conductivity and magnetic permeability. For both potential drop approaches, the edge effect and thickness effect are accounted for by introducing a correction factor estimated from theoretical models. At last, an air-cored eddy current coil is also introduced to assess electrical conductivity and magnetic permeability. In this case, the impedance of the coil is measured at multiple frequencies. The equivalent circuit of the coil is estimated and used to remove the effect of stray capacitance. Next, the measured impedance values are compared with those predicted by the finite element method to estimate electrical conductivity and magnetic permeability. As a result, depth profiles of electrical conductivity and magnetic permeability of steel samples of different case depths are obtained. Practical issues of using each of three approaches are discussed.

Ultrasonic Characterization

Characterization of Microstructure in 9 Cr- 1 Mo Alloy by Ultrasonic Measurements

---**Seung-seok Lee**, Seung-hyun Cho, Dae-chul Seo, and Choon-soo Park, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea; Weon-bae Hahn, Chong-seung Yoon, Hanyang University, Division of Materials Sciences and Engineering, Korea

---9 Cr - 1 Mo ferritic steel is currently favored structural materials working at elevated temperature and high steam pressure. The goal of this study is the characterization of microstructure in the alloy by ultrasonic method. At elevated temperature the mechanical performance in the weldment of the alloy is considered to be a life limiting factor. The simulated heat affected zone was produced by Gleeble system. A series of accelerated heat treatments were performed to simulate differing levels of thermal degradation. The variation in the ultrasonic measurement parameters such as ultrasonic nonlinearity were interpreted regarding the microstructure evolution during thermal degradation.

Ultrasonic Characterization

Ultrasonic Fields and Inspection of Huge Complex Composites

---**Chunguang Xu**, Hongbo Wang, and Dingguo Xiao, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, China

---The reliability and effectiveness of composites used widely has resulted in a significant demands for ultrasonic nondestructive testing. The model for calculating ultrasonic field in anisotropic composite material is described. Focal distance, beam spread of transmitted ultrasonic field can be obtained by measuring transmitted ultrasonic filed. In order to guarantee ultrasonic signals can more transmit through composites, the sound axis of transducer should always keep consistence in normal plane of curved surface. A twin-robot testing system is set up to inspect the complex surface automatically by ultrasonic transmitted way. The experimental results the above is effective and feasible for nondestructively ultrasonic testing huge complex composites.

Ultrasonics

Automatic Ultrasonic Inspection System for Wear Determination in Calandria Tubes of Embalse Nuclear Power Plant

---**Pablo Katchadjian**, Carlos A. Desimone, and Alejandro D. Garcia, Comision Nacional de Energia Atomica, Departamento de Ensayos No Destructivos y Estructurales, Buenos Aires, Argentina; Carlos Antonaccio, Fernando Schroeter, and Hector Molina, Nucleoelectrica Argentina S.A., Departamento de Ingenieria Mecanica, Buenos Aires, Argentina

---Embalse Nuclear Power Plant (CNE)(CANDU design) is reaching its end of life and due to elapsed operating time the problem of deformation by accelerated creep occurs in the pressure tubes (PT), leading to a possible contact between calandria tubes (CT), concentric to the PT, and some Liquid Injection Shutdown System (LISS) nozzles that pass underneath them. With determination of CT wear, after the predicted contact occurs, the wear rate of the TC could be determined and thus take less conservative measures over the remaining life of the component. This paper presents the development of an ultrasonic technique for measuring wear in CT, with nominal thickness of 1.37 mm. Because the only access is through the interior of PT, to perform this measurement it is necessary to pass through three different interfaces. The spacing between the tubes (PT-CT) is maintained between 2 and 5 mm by spacer rings. To allow propagation of ultrasonic waves the space between the tubes must be flooded with water. Due to limited access and high radiation levels at the inspection area, it was necessary to automate the testing and due to geometric configuration it was also necessary to use non-conventional ultrasonic techniques. The possible ultrasonic techniques tested are described, and detailed explanation of the non-conventional ultrasonic technique finally used. Also, the design and implementation of an inspection device and the results of measurements carried out on the mock-up to set up the system are shown.

Ultrasonics

Monitoring System for the Quality Assessment in Additive Manufacturing

---**Volker Carl**, Carl Messtechnik, Dinslaken, Germany

---Additive Manufacturing (AM) refers to a process by which a set of digital data - representing a certain complex 3dim design - is used to grow the respective 3dim real structure equal to the corresponding design. For the powder-based EOS manufacturing process a variety of plastic and metal materials can be used. Thereby, AM is in many aspects a very powerful tool as it can help to overcome particular limitations in conventional manufacturing. AM enables more freedom of design, complex, hollow and/or lightweight structures as well as product individualization and functional integration. As such it is a promising approach with respect to the future design and manufacturing of complex 3dim structures. On the other hand, it certainly calls for new methods and standards in view of quality assessment. In particular, when utilizing AM for the design of complex parts used in aviation and aerospace technologies, appropriate monitoring systems are mandatory. In this respect, recently, sustainable progress has been accomplished by joining the common efforts and concerns of a manufacturer Additive Manufacturing systems and respective materials (EOS), along with those of an operator of such systems (MTU Aero Engines) and experienced application engineers (Carl Metrology), using decent know how in the field of optical and infrared methods regarding non-destructive-examination (NDE). The newly developed technology is best described by a high-resolution layer by layer inspection technique, which allows for a 3D tomography-analysis of the complex part at any time during the manufacturing process. Thereby, inspection costs are kept rather low by using smart image-processing methods as well as CMOS sensors instead of infrared detectors. Moreover, results from conventional physical metallurgy may easily be correlated with the predictive results of the monitoring system which not only allows for improvements of the AM monitoring system, but finally leads to an optimization of the quality and insurance of material security of the complex structure being manufactured. Both, our poster and our oral presentation will explain the data flow between the above mentioned parties involved. A suitable monitoring system for Additive Manufacturing will be introduced, along with a presentation of the respective high resolution data acquisition, as well as the image processing and the data analysis allowing for a precise control of the 3dim growth-process.

Ultrasonics

The Application of High-Speed GPU-Based Finite Element Simulations to NDT
---**Peter Huthwaite**, Anton Van Pamel, Fan Shi, and Michael J. S. Lowe, Imperial College London, Department of Mechanical Engineering, London, United Kingdom

---The explicit time domain finite element method is a highly flexible approach applied to a variety of problems across NDT, to predict the behavior of waves as they interact with a domain. The highly parallel nature of the method means that it is well suited to run on a graphics card, and an open source package, Pogo (downloadable from www.pogo-fea.com), has been developed to exploit this. The high speed nature of Pogo provides opportunities to run studies which would be impossible otherwise, and three applications of this to NDT research will be presented here. Firstly, guided wave tomography excites waves between a pair of ring arrays on a pipe, then uses the dispersive nature of the waves to produce a thickness map from the measurements. The models needed are large 3D simulations, and require separate simulations to be performed for each transmitting transducer. Pogo has enabled the guided wave tomography configuration to be simulated with a large parametric sweep across defects of different widths and depths. Secondly, a similar parametric sweep is demonstrated for evaluating the performance of imaging within coarse grained materials, where the image is highly affected by the grain size, the frequency and the number of elements in the transducer array. A final study has evaluated the performance of Pogo for simulating the reflections from rough cracks using a Monte Carlo approach. This involves running many cases and analyzing the statistics of the response across a range of cracks.

Ultrasonics

Adaptive Ultrasonic Imaging with the Total Focusing Method for Inspection of Complex Components Immersed in Water

---**Léonard Le Jeune** and Sébastien Robert, CEA, LIST, Gif-sur-Yvette, F-91191, France; Philippe Dumas and Arnaud Membre, IMASONIC, Voray-sur-l'Ognon, F-70190, France; Claire Prada, Institut Langevin, 1 rue Jussieu, 75238 Paris Cedex 05, France

---Immersion inspection of components with complex geometries requires the development of adaptive imaging algorithms that are compatible with a real time processing in ultrasonic systems. The goal is to obtain an image in a structure without prior accurate knowledge of the surface geometry, which involves two key-steps: the surface geometry reconstruction and the computation of the ultrasonic paths between the probe and the image points, through the reconstructed surface. In this paper, we propose an adaptive imaging method based on the phased-array technology and the synthetic focusing algorithm Total Focusing Method (TFM). The general principle is to image the surface by applying the TFM algorithm in a semi-infinite water medium. Then, the reconstructed surface is taken into account to make a second TFM image inside the component. In the surface reconstruction step, the TFM algorithm has been optimized to decrease computation time and to limit noise in water: the TFM algorithm is applied to a sub-set of adjacent elements and this sub-aperture is translated all along the array (reduction of computation time), and the element directivity is taken into account for focusing (reduction of noise). In the second step, the ultrasonic paths through the reconstructed surface are calculated by Fermat's principle and an iterative algorithm, and the classical TFM is applied to obtain an image inside the component.
---This paper presents several results of TFM imaging in components with different geometries, and a result obtained with a new technology of probes equipped with a flexible wedge filled with water (manufactured by Imasonic).

Ultrasonics

Ultrasonic Inspection to Quantify Failure Pathologies of Crimped Electrical Connections

---**K. Elliott Cramer**, Daniel F. Perey, and William T. Yost, National Aeronautics and Space Administration, Langley Research Center, 3B E. Taylor Street, Hampton, VA 23681

---Previous work has shown that ultrasonic inspection provides a means of assessing electrical crimp quality that ensures the electrical and mechanical integrity of an initial crimp before the installation process is completed. The amplitude change of a compressional ultrasonic wave propagating at right angles to the wire axis and through the junction of a crimp termination was shown to correlate with the results of destructive pull tests, which is a standard for assessing crimp wire junction quality. Of additional concern are crimps made at high speed assembly lines for wiring harnesses, which are used for critical applications, such as in aircraft. During high-speed assembly it is possible that many faulty crimps go undetected until long after assembly, and fail in service. The position and speed of the crimping jaw become factors as the high-speed crimp is formed. The work presented in this paper is designed to cover the more difficult and more subtle area of high-speed crimps by taking into account the rate change of the measurements. Building on the previous work, we present an analysis methodology, based on transmitted ultrasonic energy and timing of the first received pulse that is shown to correlate to the gauge of the crimp/ferrule combination and the position of the crimping jaw. Results are presented demonstrating the detectability of a number of the crimp failure pathologies, such as missing strands, partially inserted wires and incomplete crimp compression. The ability of this technique to estimate crimp height, a mechanical measure of crimp quality, is discussed. A wave propagation model, solved by finite element analysis, describes the compressional ultrasonic wave propagation through the junction during the crimping process.

Ultrasonics

Characterization of Carbonation, Shrinkage, and Creep in Concrete Using Nonlinear Rayleigh Waves

---**Gun Kim**[1], Jin Yeon Kim[1], Kimberly E. Kurtis[1], and Laurence J. Jacobs[1,2], [1]Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355; [2]GW Woodruff School of Mechanical Engineering, Atlanta, GA 30332

---This research evaluates the effects of carbonation, shrinkage, and creep on the nonlinear characteristic of concrete through the application of the second harmonic generation (SHG) in Rayleigh surface waves. A 50 kHz wedge transmitter and a 100 kHz air-coupled receiver are implemented for the generation and detection of nonlinear Rayleigh waves; the non-contact receiver has the advantage of eliminating the inconsistencies associated with surface roughness and/or coupling conditions. This technique is then used to measure the relative nonlinearity parameter for specimens subjected to each of these phenomena. This relative nonlinearity parameter is defined as the ratio of the second harmonic amplitude to the square of the fundamental harmonic amplitude for increasing propagation distance. The following conclusions are drawn from the experimental results: (1) the process of carbonation in good quality concrete can decrease overall porosity, and therefore the nonlinearity parameter is significantly reduced; (2) microcracking due to shrinkage can be ameliorated through the addition of shrinkage reducing admixtures (SRA) and the nonlinearity of these are distinct; and (3) the measured nonlinearity parameter is sensitive to time-dependent creep deformation in concrete which contributes microcracking. These results clearly demonstrate the nonlinearity parameter (βre) is highly sensitive to the microstructure in cement-based materials and can be used as a reliable indicator for micro-scale damage diagnostics or health monitoring of cement-based materials.

Ultrasonics

Evaluation of Delayed Ettringite Formation Using Nonlinear Impact Resonance Spectroscopy Method

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---The use of the Nonlinear Impact Resonance Amplitude Spectroscopy (NIRAS) method to monitor the evolution of damage due to delayed ettringite formation (DEF) is examined. In practice, the temperature of concrete during casting of precast concrete members or massive concrete structures may reach more than 70°C which can provide suitable conditions for damage to occur due to DEF, particularly in concrete which is exposed to wet environments. While expansion – often in excess of 1% - is characteristic of DEF, the evolution of damage begins with microcracking. Unfortunately, there is no standard to test the susceptibility of materials or material combinations to DEF. On the other hand, NIRAS which has been successfully applied to the concrete samples affected by alkali-silica reaction, shows great sensitivity to the detection of microcracks. In this preliminary research, the NIRAS method is used to discriminate among mortar samples which are relatively undamaged and those in the early stages of DEF. The results show that NIRAS is a reliable and robust method in the detection of microcracks due to DEF, and that this technique can differentiate samples with higher and lower amount of DEF.

Ultrasonics

Near Field Effects and Estimation of Poisson's Ratio in Impact-Echo Thickness Testing

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---Reliable non-destructive estimation of thickness for plate-like concrete structures is important by many aspects such as maintenance planning, manufacturing, quality control, pay factor, safety etc. One commonly used method, for a non-destructive estimation of thickness, is the Impact-Echo (IE) method [1]. More recent studies have established the connection between the Impact-Echo method and Lamb wave theory [2]. In Lamb wave theory a plate is defined by three independent parameters (e.g. shear wave speed, Poisson's ratio and thickness). Consequently, the Impact-Echo frequency must be complemented with one velocity (compression or shear wave velocity) and Poisson's ratio for the best possible estimation of thickness. One possibility is to combine the Impact-Echo method and surface wave analysis [3]. In this paper the influence from near field effects (cylindrical spreading of waves from a point source, and interference of different wave modes) are studied for this approach. The near field effects are found to create a systematic error which underestimates the thickness with 5-15%. Results indicate that the main source of error is related to the inherently difficult task of measuring a representative compression wave velocity along the surface. Therefore, alternative approaches which are not based on measurements of the compression wave velocity are investigated for improved accuracy of the estimated thickness.---The Development Fund of the Swedish Construction Industry (SBUF) and The Swedish Radiation Safety Authority (SSM) are acknowledged for financing the study.

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Ultrasonics

Automated Flaw Detection for NDE Images

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---Many modern NDE systems generate image data. In some applications an experienced inspector performs the tedious task of visually inspecting every image to provide accurate conclusions about the existence of flaws. This labor-intensive approach can cause misses due to operator error. Automated methods can eliminate human-factors variability and improve throughput. Simple methods based on peak amplitude in an image are sometimes employed and a trained-operator-controlled refinement that uses a dynamic threshold based on signal-to-noise ratio (SNR) has also been implemented. We develop an automated and optimized detection procedure that mimics the operations of a trained operator. The primary goal of our methodology is to reduce the number of images requiring expert visual evaluation by filtering out images that have strong evidence for the existence or absence of a flaw. We use an appropriate model for the observed values of the SNR-detection criterion to estimate POD. Our methodology outperforms current methods in terms of its ability to detect flaws.---This work was performed with partial support from the Federal Aviation Administration under contract number DTFACT-09-C-00006 through the Center for Nondestructive Evaluation at Iowa State University.

Materials Characterization

Transient Potential Drop Field Measurements Using a Four Point Probe

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---In this article, transient potential drop measurement using a four-point probe is presented. Transient potential drop measurement requires direct acquisition of excitation current and time-dependent potential drop across the two pick-up pins of a four-point probe, whereas in traditional ACPD measurement, multi-frequency potential drop phasor is obtained by a lock-in amplifier, which is a zero- intermediate frequency superheterodyne receiver in nature. A custom designed instrument is built for the purpose of this experiment. The hardware utilizes a field-programmable gate array (FPGA) based Direct Digital synthesis (DDS) system to generate arbitrary voltage waveform, which is then converted to excitation current to the four-point probe. Data acquisition system composed of cascaded low noise amplifiers and high-resolution analog to digital converters acquires the waveforms of excitation current and time-dependent potential drop in real time. Comparison to analytical results on a thick conductive plate is given and potential application is also discussed.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Materials Characterization

Instrument for Fast Alternating Current Potential Drop Measurement

---**Yuan Ji**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Traditional alternating current potential drop (ACPD) measurement system is composed of lock-in amplifier, transconductance amplifier, switch box, and sampling resistor box. Using such system and ACPD probes, our group has successfully conducted many ACPD measurements for various applications and this technique has great potential for related industries. The main drawback for present system is that the measurement speed is not fast enough for practical use. In this article, the design of a fast ACPD instrument is discussed. This new instrument has integrated lock-in amplifier, high current transconductance amplifier and ultra-low noise amplifiers. It has a special burst-mode measurement regime, which significantly reduces total measurement time and makes it a feasible solution for actual field deployment. Because this instrument is fully functional as a single unit, it is very portable and consumes much less power and space than legacy systems. Combined with newly developed ACPD probes, it can be used to measure sample conductivity and permeability, coating depth, case hardness as well as small cracks. System design considerations, analog signal chain selection, digital signal processing and thermal considerations will be discussed.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Materials Characterization

Nondestructive Evaluation of Stress Corrosion Cracking in Welded 304 Stainless Steel Using Nonlinear Rayleigh Waves

---**Florian Morlock**, Katie Matlack, Jin-Yeon Kim, James J. Wall, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30318; Preet Singh, Georgia Institute of Technology, Institute of Paper Science and Technology, Atlanta, GA 30318

---This research uses nonlinear Rayleigh surface waves to characterize stress corrosion cracking (SCC) damage in welded 304 Stainless Steel (304 SS). 304 SS is widely used in reactor pressure vessels, where a corrosive environment in combination with applied stress due to high internal pressures can cause SCC. Welds and the nearby heat affected zones (HAZ) in the vessel material are especially sensitive to SCC damage. SCC damage results in microstructural changes such as dislocation formation and microcrack initiation that in the long term lead to reduced structural integrity and material failure. Therefore, the early detection of SCC is crucial to ensure safe operation. It has been shown that the microstructural changes caused by SCC can generate higher harmonic waves when excited harmonically. This research considers different levels of SCC damage induced in samples of welded 304 SS by applying stress to a specimen held in a corrosive medium (Sodium Thiosulfate). A nonlinear Rayleigh surface wave is introduced in the material and the fundamental and the second harmonic waves are measured using an air-coupled ultrasonic transducer. The nonlinearity parameter that relates the fundamental and the second harmonic amplitudes, is computed to quantify the SCC damage in each sample. These results are used to demonstrate the feasibility of using nonlinear Rayleigh waves to characterize SCC damage.

Materials Characterization

Using Nonlinear Ultrasonic Measurements to Detect and Assess the Stage of Thermal Damage in 2507 Super Duplex Stainless Steel and 9–12 Cr FM Steel

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---This study investigates early thermal aging in two different steels – 2507 super duplex stainless steel and 9-12 Cr ferritic-martensitic (FM) steel – which is caused by the formation of second phases during high temperature exposure. This study employs a recently developed nonlinear ultrasonic technique to explore the sensitivity of the nonlinear parameter. Experimental results show that the nonlinearity parameter is sensitive to certain changes in materials properties such as thermal embrittlement and hardness changes therefore; it can be used as an indicator of the thermal damage. The specimens investigated were heat treated for different holding times ranging from 0.5 h to 240 h at 450 C for the super duplex stainless steel and from 200 h to 3000 h at 650 C for 9-12 Cr FM steel. Nonlinear ultrasonic experiments are conducted for each specimen using a wedge transducer to generate and an air-coupled transducer to detect Raleigh surface waves. The amplitudes of the first and second order harmonics are measured at different propagation distances and these amplitudes are used to obtain the relative nonlinearity parameter for each specimen with different aging periods. The nonlinear ultrasonic obtained results are compared with independent mechanical measurements and metallographic images. This research proposes the nonlinear ultrasonic technique as a nondestructive evaluation tool not only to detect thermal damage in early stages, and also to qualitatively assess the stage of thermal damage.

Materials Characterization

Application of the Wavelet Transform to Acoustic Emission Signals Processing to Distinguish Corrosion Type

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---The acoustic emission technique is the result of transient elastic wave propagation generated by a rapid release of energy within a material, and was used to detect and classify corrosion damage. Steel sheets ASTM 283 Grade C 120 mm (length), 120 mm (width) and 6.35 mm (thickness) were used as specimen. During the tests, the samples were first exposed to a solution $H2SO4$ + $Na2SO4$ to generate uniform corrosion damage, then a solution $FeCl3$ was used to generate pitting corrosion, both were conducted at room temperature. The aim of this work is to distinguish uniform corrosion and pitting corrosion damage via acoustic emission signals using Continuous Wavelet Transform that proved to be a good tool to distinguish different corrosion kind acoustic signals.

Materials Characterization

Relation Between Low-Frequency Components in Ultrasonic Waves Propagating Through Contacting Solids and Acoustic Emission Waves

---**Hirotaka Tanaka**, Yuji Kato, and Toshihiko Sugiura, Keio University, Department of Mechanical Engineering, Yokohama, Kanagawa, Japan

---One of challenging subjects of ultrasonic testing is detection of closed cracks. Cracks in solids can be detected by ultrasonic testing if they are open. However, it is difficult to detect them if they are closed. Nonlinear ultrasonics is expected as a useful method for detection of closed cracks in structures. This study experimentally examined transmission of ultrasonic waves through the interface between contacting solids. Two metal blocks were stacked and loaded by a compressor for simulating a closed crack. The transmit frequency was changed in the range of 1.0-2.0 MHz and several types of surface roughness of specimens were used. As a result, generation of low-frequency components of 600 kHz was found regardless of the transmit frequency. Frequency of acoustic emission (AE) waves is usually 100 kHz – 1000 kHz in metal materials. Such a feature of AE waves is similar to that of low-frequency components found in our experiments. We investigated and discussed a relation between generation of low-frequency components in ultrasonic waves and AE waves.

Materials Characterization

Nonlinear Parameter Calculation in Consideration of the Second Harmonic Frequency Component of Incident Ultrasonic Waves

---**Seung Hyun Cho**, Choonsu Park, and Dea Cheol Seo, Korea Research Institute of Standards and Science, Yuseong-gu, Daejon, South Korea

---In field of a classical nonlinear ultrasonic NDE, an elastic nonlinear parameter is calculated from a second harmonic frequency component under the assumption that an input ultrasound has only pure single frequency component. To satisfy the assumption, much effort should be exerted like a delicate experimental setup such as highly linear signal drivers and transducers, perfect contact condition between sensors and a specimen. Otherwise, the measurement may lead to poor experimental repeatability, large deviation of the measured value, and, most of all, difficulty in measuring absolute nonlinear parameter. Actually, the second harmonic frequency component is not easy in real situations. In this investigation, we present a method to measure nonlinear parameter under the assumption the incident ultrasonic wave has not only main exciting frequency but also its second harmonic frequency component caused by the nonlinearity of the instruments and an ill-conditioned contact. A model was made to calculate elastic nonlinear parameter in consideration of second harmonic component of an input incident wave. The validity of the proposed model was verified with the simulated signals from finite element analysis. 1-dimensional time transient analysis was carried out to obtain simulated sample signals, which was applied to the proposed model. The calculated elastic nonlinear parameter with the proposed model showed good agreement with the nonlinear parameter used in finite element analysis. Experimental verification was also tried to carry out with some actual specimens, which gave meaningful results.

Materials Characterization

Characterization of 3D Rapid Prototyped Polymeric Material by Ultrasonic Methods

---**Richard A. Livings**, Vinay Dayal, and Dan J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011

---Rapid prototyped parts are quickly becoming a viable alternative for manufacturers. Although the polymeric material is initially isotropic, the printing process introduces a level of anisotropy. This work characterizes the elastic and acoustic properties of the material, after printing, using ultrasonic methods. The elastic constants and the level of anisotropy are determined by measuring the ultrasonic wave velocities. The dispersion and attenuation characteristics are also determined to provide a basis for ultrasonic flaw detection. The ultrasonic results for the elastic constants are compared to the mechanical evaluation of test coupons.

Signal Processing

Clutter Noise Reduction for Phased Array Imaging Using Spatial-Frequency Polarity Coherence in Ultrasonic NDE

---**Rui Gongzhang**, Anthony Gachagan, and Bo Xiao, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom

---A number of materials used in industry exhibit highly-scattering properties which can reduce the performance of conventional ultrasonic NDE approaches. Moving Bandwidth Polarity Thresholding (MBPT) is a robust frequency diversity based algorithm for scatter noise reduction in single A-scan waveforms [1]. This approach uses sign coherence across a range of frequency bands to reduce grain noise and improve Signal to Noise Ratio. Importantly, for this approach to be extended to array applications, spatial variation of noise characteristics must also be considered. This paper presents a new spatial-frequency diversity based algorithm for array imaging, extended from MBPT. Each A-scan in the full matrix capture (FMC) array dataset is partitioned into a serial of overlapped frequency bands and then undergoes polarity thresholding to generate sign-only coefficients indicating possible flaw locations within each selected band. These coefficients are synthesized to form a coefficient matrix using a delay and sum approach in each frequency band. Matrices produced across the frequency bands are then summed to generate a weighting matrix, which can be applied on any conventional image. A 5MHz linear array has been used to acquire data from both austenitic steel and high nickel alloy (HNA) samples to validate the proposed algorithm. Around 60dB background noise suppression for both samples are observed after applying this approach. Importantly, three side drilled holes and the back wall of the HNA sample are clearly enhanced in the processed image, with a mean of 133% Contrast to Noise Ratio improvement when compared to a conventional TFM image.---
The authors thank E.ON for providing the samples.

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Signal Processing

Speckle Suppression Using Adaptive Frequency Compounding in Ultrasound Nondestructive Evaluation of Coarse-Grained Material

---**Bo Xiao**, Rui Gongzhang, Timothy Lardner, Richard L. O'Leary, and Anthony Gachagan, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, United Kingdom

---Coarse-grained engineering materials exhibiting heterogeneous and anisotropic microstructure are used extensively in many industrial sectors. Inspecting such materials using ultrasound suffers backscattered signals from grain boundaries resulting in strong speckle noise, which reduces image contrast and increases difficulty in image interpretation. In this paper, we propose an algorithm to adaptively compound images which are acquired in different frequency channels (FC), in order to remove or minimize speckle. Most existing image compounding algorithms are point-wise and based on order statistics estimation, which implicitly assume speckle is spatially and spectrally uncorrelated, leading to limited success in speckle suppression. The proposed method applies spatially variant weightings which are calculated to account for both spatial correlation and inter-FC correlation of speckle noise and flaw echo signals. To validate this method, experiments on two highly scattering samples were conducted: an Inconel 625 block with two side-drilled holes and a steel weld block with an implanted tilted flaw, simulating lack of fusion. Speckle point was found to be less spatially and spectrally correlated than flaw point, yielding smaller compounding output. By applying the proposed adaptive compounding algorithm, flaw-to-noise ratio (FNR) of the Inconel block has achieved a ~45 dB enhancement compared with minimization compounding, whilst ~60dB FNR improvement for the steel weld block is demonstrated. It is concluded that the proposed algorithm can significantly suppresses speckle and enhance flaw characterization without spatial resolution loss.---The authors acknowledge support from EPSRC (EP/I019731/1) Rolls Royce, Shell, National Nuclear Laboratories, AMEC, and Weidlinger Associates under the auspices of UK RCNDE.

Signal Processing

Surface Reconstruction Methods with Phased-Arrays for Adaptive Ultrasonic Imaging in Complex Components Immersed in Water

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---Ultrasonic immersion testing of structures with complex geometries may be significantly improved by using phased-arrays and specific adaptive algorithms. It is possible to image flaws inside a complex structure without accurate knowledge of the surface geometry. The general principle of adaptive methods can be summarized in two steps: first, the surface geometry is reconstructed with ultrasonic measurements; next, the ultrasonic paths through the reconstructed surface are calculated in order to adapt focusing laws. In this context, this paper presents a review of the different surface reconstruction methods available in the CIVA software and used for ultrasonic adaptive imaging. These methods are based either on a time-of-flight measurement or on an image processing (edge detection). A new method based on the ‘Surface Adaptive ULtrasound’ (SAUL) technique, originally developed for immersion inspection of aeronautical composite structures, is also presented and compared to the others in terms of reconstruction speed and accuracy. Finally, we present a generalized adaptive method, based on the Total Focusing Method (TFM), where flaws are imaged with half-skip ultrasonic paths. In this method, both the surface and the back-wall of a complex structure are reconstructed before imaging flaws.

Signal Processing

Structural Health Monitoring Method Based on the Entropy of an Ultrasonic Sensor Network for a Plate-Like Structure

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---Piezoelectric ultrasonic sensors used to propagate guided waves can be potentially implemented to inspect large areas in engineering structures. However, the inherent dispersion and noise of the guided acoustic signals, multiple echoes in the plate as well as a lack of an approximate or exact model limits its use as a plausible continuous structural health monitoring system. In this work, the implementation of a network of piezoelectric sensors randomly placed on a plate-like structure to detect and locate artificial damage is studied. A sensor network of randomly located 1MHz transducers working in a pitch–catch configuration was set on an aluminum thin plate with 0.075 inches in thickness. Signals were analyzed in time-scale domain by the continuous wavelet transform. The objectives in this work were twofold, first to develop a damage index using the entropy of the ultrasonic waves generated by a sensor network; and second to implement time of arrival (TOA) and time-difference of arrival (TDOA) algorithms on the gathered signals for damage location of an artificial circular discontinuity. Our preliminary test results show that the proposed methodology provides sufficient information for damage detection which, once combined with the TOA and TDOA algorithms, allows localization of the damage.

Signal Processing

Detection of Structural Damage in Multiwire Cables by Monitoring the Entropy of Continuous Wavelet Transform

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---Multiwire cables are widely used in engineering structures such as in mechanical supports, energy power cables and stay cables in bridges. They are subjected to various environmental factors including dynamic and static loads which can affect their performance and lead to failure; thus, requiring continuous structural health monitoring (SHM). Ultrasonic wave propagation, has been proposed as a potential tool for damage detection. However, to model the ultrasonic wave propagation in these cables is difficult due to variables such as friction, acoustic dispersion, signal noise and mode conversion. In this work, guided waves were propagated in a test sample of an aluminum cable steel reinforced (ACSR) with 0.85in in diameter and 3.86ft in length. A tone burst signal generated by a function generator and two 1MHz piezoelectric transducers were used in a pitch-catch configuration. A continuous wavelet transform algorithm (CWT) was then implemented on the captured signals taken from test cables having various degrees of damage. A damaged recognition method based on the estimation of the entropy of the wavelet representation of the captured signal is proposed. To estimate the entropy of the system, the probability distribution was measured at each scale of the CWT and normalized by the probability distribution of the entire wavelet transform. The objectives were twofold: first, to develop an algorithm based on the entropy of the CWT of the received signals; and second, to determine the correlation between the damage extension and the entropy of the system. Preliminary test results show that there is a significant correlation between the wavelet transform entropy and the degree of damage. The proposed method based on entropy of the wavelet transform was able to correctly discriminate healthy from damaged cables.

Signal Processing

Influence of Curvature of Wire-Ropes on Guided Wave Propagation

---**Kousuke Kanda** and Toshihiko Sugiura, Keio University Department of Mechanical Engineering, Kohokuku, Kanagawa, 223-8522, Japan

---Guided waves can propagate along waveguides such as long pipes and rails with low attenuation. Therefore, using guided waves is ideal for nondestructive testing, especially of wire-ropes that requires long time by conventional methods of testing. But the complicated twisted structure of a wire-rope makes practical use of guided waves difficult. To solve this problem, in previous studies, experiments using laser ultrasonic transducers and analytical modeling of helical waveguides by semi-analytical finite element methods were presented. However, more studies are required for explaining practical phenomena of guided waves in a wire-rope. As a fundamental step toward practical use of guided waves for a wire-rope, this research evaluates propagation modes of guided waves propagating through a structure with curvatures by analysis and experiment. Dispersion curves of the phase velocity and of the group velocity in a straight columnar section and in curved columnar sections having various curvature radii were numerically derived and compared with each other. Further, we experimented on wire-ropes with various curvatures. As a result, we confirmed influence of curvature of wire-ropes on guided wave propagation through them.

Advanced Materials

Langmuir-Blodgett Bacteriorhodopsin Monolayer Surface CARS Spectroscopy

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---The development of Langmuir-Blodgett (LB) technology of organic monolayer allows to hope for production of molecular electronic devices. Bacteriorhodopsin (BR) may be used as one of the promising materials for such devices. BR monolayer spectral studies are informative but not sufficiently sensitive. The report offers the method of enhancing BR spectral measurement sensitivity. The following circumstances are taken into account: 1) Frequency ω1, of the exciting light should be equal to that of transition from the ground state to the excited one. In this case at the frequency ω1 ~ 569 nm increases by a factor of 105; 2) It is suggested to examine CARS spectra instead of RS spectra. As a result, signal IAS ~ I2(ω1)I(ω2), where I(ω1) and I(ω2) are the fields generated by two laser sources, which appreciably increase; 3) BR monolayer can be deposited on a metallic film, which, in turn, is deposited on the prism base. If the incident radiation is effectively transformed into surface plasma waves, the cross section of the process RS increases approximately by 6 orders. Utilization of plasmon waves imposes limits on the incident radiation energy. It has to be not more than 25 J/cm2. Thus we get ~ 109 photons per pulse in anti-Stokes radiation that is sufficient for experiments on LB bacteriorhodopsin monolayer studies.

Advanced Materials

Study of Ultrasonic Characteristics in Single-Layer Carbon Fiber Reinforced Plastic

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---Carbon fiber reinforced plastic (CFRP) has been applied in a large range of civil aircraft structures. However, the CFRP product is likely to contain some defects, such as a crack or bubbles as there are many instable factors during the manufacturing process. Since the defects are inevitable, detection technologies are needed to control the quality or ensure the safe use of CFRP products. Ultrasonic testing is an effective Nondestructive Testing (NDT) method. In order to ensure effective detection and qualitative analysis of defects, analyzing ultrasonic characteristics in the CFRP is useful. In this paper, ultrasonic wave propagation in a single layer CFRP has been studied. An ultrasonic composite finite element model has been established at first. Then, the ultrasonic propagation characteristics in homogeneous anisotropic medium have been discussed. Finally, a single layer of CFRP has been selected as the study object, in which the ultrasonic field has been simulated from the perspective of material properties.

Advanced Materials

NDE of Transparent Protective Panels

---**Dan Barnard**, Frank Margetan, Chien-Ping Chiou, Aaron Herman, and Brittney Pavel, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---In this paper we discuss nondestructive testing of several varieties of transparent protective panels fabricated from layers of glass, polymer and adhesive. We report measurements of sound speed and attenuation on single-layer specimens of the polymer and the two types of glass used in the panels. We then discuss the results of various NDE inspections employing air-coupled and immersion ultrasound and terahertz electromagnetic radiation. For some panels, ultrasonic through-transmission C-scans reveal interesting patterns of signal amplitude and phase variations. Possible explanations for these variations are explored. We also discuss the usefulness of the NDE techniques to quantify panel fabrication irregularities, such as variations in adhesive thickness with position.---This material is based on work supported the Army Research Laboratory as part of cooperative agreement number W911NF0820036 at the Center for Nondestructive Evaluation at Iowa State University.

Advanced Materials

Inspection Techniques for Adhesively Bonded Stacked Open Honeycomb Core Composites

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---Honeycomb sandwich composites are used extensively in the aerospace industry to provide stiffness and thickness to lightweight structures. A common fabrication method for thick, curved sandwich structures is to stack and bond multiple honeycomb layers prior to machining core curvatures. Once bonded, each adhesive layer must be inspected for delaminations and the presence of unwanted foreign materials such as release film. From a manufacturing and cost standpoint, it can be advantages to inspect the open core prior to face sheet closeout in order to reduce end-article scrap rates. However, by nature, these honeycomb sandwich composite structures are primarily manufactured from low permittivity and low loss materials making detection of delamination and some of the foreign materials (e.g., release film) which also are low permittivity and low loss, quite challenging in the microwave and millimeter wave regime. Likewise, foreign materials such as release film in adhesive layers can be sufficiently thin as to not cause significant attenuation in through-transmission ultrasonic signals, making them difficult to detect. This paper presents a collaborative effort intended to explore the efficacy of different non-contact NDI techniques for detecting flaws in a stacked open fiberglass honeycomb core panel. These techniques primarily included air-coupled through-transmission ultrasonics, single-sided wideband synthetic aperture microwave and millimeter-wave imaging and lens-focused technique. The goal of this investigation has been to not only evaluate the efficacy of these techniques, but also to determine their unique advantages and limitations for evaluating parameters such as flaw type, flaw size and flaw depth.

Advanced Materials

Experimental Studies on NRUS Behavior of Impact Damaged Composite Laminates

---**Hyunjo Jeong**, Wonkwang University, Mechanical and Automotive Engineering, Iksan, Jonbuk, Korea; Daniel Barnard, Iowa State University, Center for NDE, Ames, IA 50011

---Nonlinear acoustic methods or Nonlinear Elastic Wave Spectroscopy (NEWS) techniques are widely used these days for damage assessment in a large group of materials including metals, rocks and composites. Nonlinear resonant ultrasound spectroscopy (NRUS) is one of those techniques and has proved to be valuable for damage detection because of its high sensitivity. NRUS is a vibration-based technique exploiting the nonlinear resonance behavior of damaged materials. In NRUS, the resonant frequency of an object is sought as a function the excitation level. As the excitation level increases, the material nonlinearity is manifested by a shift in the resonance frequency. In this work, NRUS experiments were conducted on intact and impact-damaged carbon fiber-epoxy composite laminates. Both fundamental and higher harmonic resonance were measured and analyzed. It was observed that undamaged samples exhibited some baseline nonlinearity. With increase in impact damage, nonlinearity increased beyond the baseline nonlinearity. The hysteretic nonlinear parameter was extracted from the change in resonant frequency with peak strain amplitude. The higher order hysteretic parameters were found to be more sensitive to conventional first order parameters for given damage level.---This work was supported by National Research Foundation of Korea (2013-R1A2A2A01016042).

Advanced Materials

Ultrasonic Impact Damage Assessment in Woven Composite Materials

---Emira Mannai, **Benjamin Lamboul**, and Jean-Michel Roche, Onera - The French Aerospace Lab, F92322, avenue de la Division Leclerc, F923322 Châtillon, France

---Woven composite materials are increasingly used in the aeronautical industry for their flexibility in the design of parts with complex shapes (e.g. fan blades), and their high tolerance to impacts compared to standard composite laminates made of unidirectional plies. In these materials, the fiber reinforcement consists of yarns woven in two-dimensional or even three-dimensional patterns. Accurate numerical modeling of the damage mechanisms and the residual mechanical resistance of this type of material after impact is still under investigation and requires experimental data to validate and confront model predictions to real observations. Unfortunately, the observed damage patterns are very complex and consist of multiple, diffuse cracking at different scales. These damage patterns make the most standard NDT techniques (infrared thermography and ultrasonic testing) not readily applicable or not fully effective. For ultrasonic inspections, two major difficulties may be pointed out. First, the fiber reinforcement of this type of material is very echogenic at the usual wavelengths and generates what could be called a "structural noise". Second, the defects are small in size (much smaller than a delamination after impact in a standard laminate), and not necessarily favorably oriented for detection (that is, normal to the insonification direction), due to the fibers undulation. This paper aims at assessing how much information can be retrieved from ultrasonic scans of impacted woven composites in the perspective of numerical predictions validation. The "structural noise" amplitude of the unaltered woven composite was first measured with depth using single element transducers with different nominal center frequencies. The noise level was then compared to ultrasonic echo amplitudes obtained from flat bottom holes of different diameters and orientations drilled in the same material. In a first approach, the obtained curves provided a depth-dependent binary thresholding value to highlight the impact damage from the structural noise with depth. Some volume data processing methods (3D segmentation, volume rendering) were finally tested on the obtained data to better render the spatial distribution of damage compared to conventional C-scans, and to infer potentially valuable statistics for numerical scientists.

Composites

Characterization of Fiber Content and Distribution in Natural Fiber-Reinforced Composites by Ultrasonic Techniques

---**Inna Seviaryna** and Elena Maeva, University of Windsor, Physics Department, Windsor, Ontario, Canada; Jimi Tjong, Ford Motor Company, Powertrain Engineering Research and Development Centre, Windsor, Ontario, Canada

---The natural fiber reinforcement of polymers has several advantages over reinforcement with synthetic fibers such as lower cost, wide availability and biodegradability. Use of natural fiber reinforced composites (NFRC) has become very popular in the automotive, construction and other industries. An increasing request for improvement in vehicle energy efficiency and environmental concern has forced the automotive industry to develop new lightweight bio-based composite materials. Most of the NDE methods in the automotive industry are adjusted to the evaluation of synthetic fiber composites and should be adapted to this change of materials as well. The objective of this research is to study the feasibility of using ultrasonic methods to evaluate quantitatively the microfibers content and their distribution in natural fiber reinforced composites. The important viscoelastic properties of novel NFRC were examined through a combination of experimental and theoretical approaches. A series of samples with different fiber content was produced and tested. The pulse-echo technique was used for qualitative estimation and quantitative measurements of basic viscoelastic parameters of polypropylene-based composites filled with microfibers. The experiments were carried out on a custom designed ultrasonic system in a wide frequency range (1-25 MHz). Anisotropy measurements provided information about preferential fibers orientation which appears during extrusion process. It was found that fiber content correlates with both sound speed and attenuation but the effect on sound attenuation is much more pronounced. The frequency dependencies of these parameters in the range of 1-25MHz are in good correlation with the model prediction. Scanning acoustic microscopy was used to visualize homogeneity of fiber distribution in the polymer matrix as well as to detect the major types of defects such as voids, cracks, and fiber agglomerations. This study provides a solid basis for the development of technology for ultrasonic in-process monitoring of material formation. It should provide quick feedback in optimizing the technological regime settings to produce composites with the required mechanical performance.---This Project was funded by Automotive Partnership Canada NSERC.

Session 29

Thursday, July 24, 2014

SESSION 29

RADIOGRAPHY II

Joseph N. Gray, Chairperson

Cottonwoods-Firs

3:30 PM **Fast and Low-Dose Computed Laminography Using Compressive Sensing Based Technique**
---**Sajid Abbas**, Miran Park, and Seungryong Cho, Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, Daejeon, South Korea

3:50 PM **CFRP Inner Structure and Defect Characterization Using μ-Computed Tomography**
---**Rainer Stoessel** and Denis Kiefel, Airbus Group Innovations, TX3 H, 81663 Munich, Germany

4:10 PM **Quantitative Impact Characterization of Aeronautical CFRP Materials with Non-Destructive Testing Methods**
---Denis Kiefel and **Rainer Stoessel**, Airbus Group Innovations, TX3HG, Willy-Messerschmitt-Strasse, 81663 Munich, Germany; Christian Grosse, Technical University Munich, Chair of Non-destructive Testing, Munich, Germany

3:30 PM

Fast and Low-Dose Computed Laminography Using Compressive Sensing Based Technique

---**Sajid Abbas**, Miran Park, and Seungryong Cho, Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, Daejeon, South Korea

---Computed laminography (CL) is well known for inspecting microstructures in the materials, weldments and soldering defects in high density packed components or multilayer printed circuit boards. The overload problem on x-ray tube and gross failure of the radio-sensitive electronics devices during a scan, are among important issues in CL which needs to be addressed. The sparse-view CL can be one of the viable option to overcome such issues. In this work a numerical aluminum welding phantom was simulated to collect sparsely sampled projection data at only 40 views using a conventional CL scanning scheme i.e. oblique scan. A compressive-sensing inspired total-variation (TV) minimization algorithm was utilized to reconstruct the images. It is found that the images reconstructed using sparse view data are visually comparable with the images reconstructed using full scan data set i.e. at 360 views on regular interval. We noticed that tiny structures such as copper and tungsten slags, and copper flakes in image reconstructed using sparsely sampled data are qualitatively comparable with the corresponding structure present in the fully sampled data case. A blurring effect was also noticed near the edges of few pores at the bottom of reconstructed image using sparsely sampled data, despite this the overall image quality is reasonable for fast and low-dose NDT.

3:50 PM

CFRP Inner Structure and Defect Characterization Using µ-Computed Tomography

---**Rainer Stoessel** and Denis Kiefel, Airbus Group Innovations, TX3 H, 81663 Munich, Germany

---So far µ-Computed Tomography (µ-CT) techniques were mainly used only for defect detection in CFRP. But now there is a growing demand to characterize the inner structure and defects to gather information for design, production control, and repair. At Airbus Group Innovations we operate a µ-Computed Tomography system that was especially designed for CFRP testing. It is an open system so that different kinds of acquisition, reconstruction, and data evaluation tools can be used. In the paper the results obtained with this system and the evaluation tools will be presented. This includes defect detection, porosity and crack evaluation as well as main orientation analysis.

4:10 PM

Quantitative Impact Characterization of Aeronautical CFRP Materials with Non-Destructive Testing Methods

---Denis Kiefel and **Rainer Stoessel**, Airbus Group Innovations, TX3HG, Willy-Messerschmitt-Strasse, 81663 Munich, Germany; Christian Grosse, Technical University Munich, Chair of Non-destructive Testing, Munich, Germany

---In recent years, an increasing number of safety-relevant structures are designed and manufactured from carbon fiber reinforced polymers (CFRP) in order to reduce weight of airplanes by taking the advantage of their specific strength. Non-destructive testing (NDT) methods for quantitative defect analysis of artificial impact damages are liquid- or air-coupled ultrasonic testing (UT), phased array techniques, and active thermography (IR). The advantage of these testing methods is the applicability on large-scale areas. However, their quantitative information is mainly limited on impact localization and size. In addition to these techniques, Airbus Group Innovations operates a Micro X-Ray Computed Tomography (µ-XCT) system, which was purpose developed for CFRP characterization. It is an open system which allows different kinds of acquisition, reconstruction, and data evaluation. One great advantage of this µ-XCT system is its high resolution with 3-dimenstional analysis and visualization opportunities, which enables to gain important quantitative information for composite part design and stress analysis. Within this study, different NDT methods will be compared at several CFRP samples with specified artificial impact damages. Furthermore, novel evaluation and visualization methods for impact analyzes are developed and will be presented in detail.

Session 30

SESSION 30
SIGNAL PROCESSING
Ali Shariati, Chairperson
Peregrines

3:30 PM **The Effect of Surface Roughness on Extrapolation from C-Scan Data Using Extreme Value Theory**
---**Daniel Benstock** and Frederic Cegla, Imperial College, Mechanical Engineering, London SW7 2AZ, United Kingdom

3:50 PM **A Synthetic Aperture Routine to Approximate Rayleigh Surface Wave Imaging Scans Over Anisotropic Media**
---**Matthew Cherry**[1], Shamachary Sathish[2], and Adam Pilchak[3], [1]Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433-7817; [2]University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45469-0020

4:10 PM **Signal Enhancement by Controlled Orthogonally Polarized Shear Waves**
---**Masanori Kitaoka**, Hisashi Endo, and Yoshiaki Nagashima, Hitachi Research Laboratory, Hitachi Ltd, Hitachi, Ibaraki, Japan

4:30 PM **Image Processing Algorithms for Automated Analysis of GMR Data from Inspection of Multilayer Structures**
---S. Safdarnejad[1], **O. Karpenko**[1], L. Udpa[1], S. S. Udpa[1], and A. Tamburrino[1], [1]Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48864-1226

4:50 PM **Polychromatic Sparse Image Reconstruction and Mass Attenuation Spectrum Estimation via B-Spline Basis Function Expansion**
---**Renliang Gu** and Aleksandar Dogandžić, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

5:10 PM **Oversampling in VVS as a Means to Recover Higher Modes of Vibration**
---**A. Shariati** and T. Schumacher, University of Delaware, Department of Civil Engineering, 314 Dupont Hall, Newark, Delaware

3:30 PM

The Effect of Surface Roughness on Extrapolation from C-Scan Data Using Extreme Value Theory

---**Daniel Benstock** and Frederic Cegla, Imperial College, Mechanical Engineering, London SW7 2AZ, United Kingdom

---Ultrasonic thickness C-scans are a key tool in the assessment of the condition of engineering components. C-scans provide information of the wall thickness over the entire inspected area. Full inspection of a component is time consuming, costly and sometimes impossible due to access constraints. Therefore, the condition of the whole structure is sometimes estimated by extrapolation of data from a sample where C-scan information is available. Extreme value theory (EVT) provides a framework by which one can extrapolate to the size of the worst case defect from a small inspected sample area of a component. The framework and assumptions of EVT are discussed, with experimental and simulated examples. The influence of both the surface roughness and the timing algorithm, used to extract thickness measurements from the collected ultrasonic signals, is also analyzed. It can be shown that for uniformly rough surfaces the C-scan data can lead to conservative estimates of the size of the worst case defect.

3:50 PM

A Synthetic Aperture Routine to Approximate Rayleigh Surface Wave Imaging Scans Over Anisotropic Media

---**Matthew Cherry**[1], Shamachary Sathish[2], and Adam Pilchak[3], [1]Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433-7817; [2]University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45469-0020

---A method for determining the effective Rayleigh surface wave (RSW) velocity under the probe during the RSW imaging experiment described in [1] was developed. The synthetic aperture routine can take in polycrystalline data with arbitrary c-axis orientation for each crystal and calculate the total effect that the crystals below the probe has on the response. It relies on calculation of RSW velocity in arbitrary directions for hexagonal crystals by applying numerical methods to the theory contained in [2] and [3]. In this paper, the method will be summarized and examples will be shown that demonstrate the feasibility of the routine for approximating scans over the surface of samples. Application of the method in the context of material characterization will be discussed.

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4:10 PM

Signal Enhancement by Controlled Orthogonally Polarized Shear Waves
---**Masanori Kitaoka**, Hisashi Endo, and Yoshiaki Nagashima, Hitachi Research Laboratory, Hitachi Ltd, Hitachi, Ibaraki, Japan

---A novel ultrasonic testing system for signal enhancement has been developed. This system simultaneously transmits and receives two orthogonally polarized shear waves. The polarization states are variable by controlling their amplitudes and the time delay between wave generations. These waves are superimposed in the material to be tested and travel along the same propagation path; therefore, the system has the potential to extract polarization-dependent information about the defects, grains, inclusions and so on from the received signals. This information is valid for detecting and characterizing small defects in materials with birefringence, i.e., polarized shear waves propagate along the principal axes with different velocities. Enhancement of the desired signal is achieved by cross-correlation analysis of two polarized waves. When the phases of the desired reflected or scattered waves are matched to each other by adjusting the time delay, the correlation of the two waves is maximized. Undesired signals included in uncorrelated signals are canceled. A specially designed probe, which is capable of generating well-controlled polarization states, realizes this signal enhancement technique. The probe contains two orthogonally oriented and longitudinally layered piezoelectric transducers. The enhancement of B-scan images produced by scanning this probe over specimens having simulated defects is demonstrated.

4:30 PM

Image Processing Algorithms for Automated Analysis of GMR Data from Inspection of Multilayer Structures
---S. Safdarnejad[1], **O. Karpenko**[1], L. Udpa[1], S. S. Udpa[1], and A. Tamburrino[1],
[1]Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48864-1226

---Eddy current probes with Giant Magnetoresistive (GMR) elements have recently emerged as efficient tool for rapid scanning of riveted joints and other complex multilayered structures. However, analysis of signals obtained from GMR sensor arrays is challenging due to existence of closely spaced fasteners, nearby part edges, subsurface structures, and sensitivity variation of elements in an array. In this paper, finite element modeling (FEM) of riveted aluminum samples is used to simulate the effect of complex multilayer geometries on GMR measurements in order to develop robust algorithms that consistently detect indications of cracks in the 2nd layer. Based on the simulation results and artifacts in experimental data, the proposed algorithm incorporates compensation of sensitivity variation of elements of the array, suppression of signals from surrounding structures, and identification of defect pattern in the enhanced signal. Simulation results illustrate that the displacement of the symmetry axis in the rivet suppressed signal and raw measurement data can serve as a representative feature for detecting defects. Initial results demonstrate that the proposed image processing method increases the probability of detection (POD) of 2nd layer defects in complex riveted structures.---This material is based upon work supported by the AFRL under contract No. FA8650-10-D-5201, Task Order 014.

4:50 PM

Polychromatic Sparse Image Reconstruction and Mass Attenuation Spectrum Estimation via B-Spline Basis Function Expansion

---**Renliang Gu** and Aleksandar Dogandžić, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---We develop a sparse image reconstruction method for polychromatic CT measurements under the blind scenario where the material of the inspected object and the incident energy spectrum are unknown. To obtain a parsimonious measurement model parameterization, we first rewrite the measurement equation using our mass-attenuation parameterization, which has the Laplace integral form. The unknown mass-attenuation spectrum is expanded into basis functions using a B-spline basis of order one. We develop a block coordinate-descent algorithm for constrained minimization of a penalized negative log-likelihood function, where constraints and penalty terms ensure nonnegativity of the spline coefficients and sparsity of the density map image in the wavelet domain. This algorithm alternates between a Nesterov's proximal-gradient step for estimating the density map image and an active-set step for estimating the incident spectrum parameters. Numerical simulations demonstrate the performance of the proposed scheme.

5:10 PM

Oversampling in VVS as a Means to Recover Higher Modes of Vibration
---**A. Shariati** and T. Schumacher, University of Delaware, Department of Civil Engineering, 314 Dupont Hall, Newark, Delaware

---Vibration-based structural health monitoring (SHM) techniques require modal information from the monitored structure in order to estimate the location and severity of damage. Natural frequencies also provide useful information to calibrate finite element models. There are several types of physical sensors that can measure the response over a range of frequencies. For most of those sensors however, accessibility, limitation of measurement points, wiring, and high system cost represent major challenges. Recent optical sensing approaches offer advantages such as easy access to visible areas, distributed sensing capabilities, and comparatively inexpensive data recording while having no wiring issues. In this research we propose a novel methodology to measure natural frequencies using digital video cameras based on virtual visual sensors (VVS). In our initial where we worked with commercially available inexpensive digital video cameras we found that for multiple degrees of freedom (DOF) systems it is difficult to detect all of the natural frequencies simultaneously due to low quantization resolution. In this presentation we show how oversampling enabled by the use of high-end high-frame video cameras enabled us to recover all of the three natural frequencies from a three DOF lab-scale building.

Session 31

SESSION 31

ROBOTICS

Don Palmer and Frank Reed, Co-Chairpersons
Pines-Willows

3:30 PM **Automated Metrology and NDE Measurements for Increased Throughput in Aerospace Component Manufacture**
---**Charles N. MacLeod**, S. Gareth Pierce, Maxim Morozov, Rahul Summan, and Gordon I. Dobie, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, United Kingdom; Paul McCubbin, Coreen McCubbin, Scott Dearie, and Gavin Munro, Spirit AeroSystems (Europe) Limited, Prestwick, Scotland, United Kingdom

3:50 PM **Automated Full Matrix Capture for Industrial Processes**
---**Roy H. Brown**, S. Gareth Pierce, Jerzy Dziewierz, Joseph Jackson, Timothy Lardner, Charles MacLeod, and Maxim Morozov, University of Strathclyde, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; Ian Collison, Rolls-Royce plc, Derby, United Kingdom; Ben Dutton, Manufacturing Technology Centre Ltd., Coventry, United Kingdom

4:10 PM **Robotic Path Planning for Non-Destructive Testing of Complex Shaped Surfaces**
---**Carmelo Mineo** and Stephen G. Pierce, University of Strathclyde, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; Pascual I. Nicholson and Ian Cooper, TWI, Technology Centre Wales, Port Talbot, United Kingdom

4:30 PM **The Computational Enhancement of Automated Non-Destructive Inspection**
---**Nicholas Brierley**, Trevor Tippetts, and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

4:50 PM **Development of RFECT System for ILI Robot of 16 Inch Unpiggable Gas Pipeline**
---**Jaeha Park**, Joengwon Park, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Mechanical Engineering, Suwon, Gyeonggi-do, South Korea; Huiryong Yoo, Sungho Cho, and Yongwoo Rho, Korea Gas Corporation, R&D Division, Incheon, South Korea

3:30 PM

Automated Metrology and NDE Measurements for Increased Throughput in Aerospace Component Manufacture

---**Charles N. MacLeod**, S. Gareth Pierce, Maxim Morozov, Rahul Summan, and Gordon I. Dobie, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, United Kingdom; Paul McCubbin, Coreen McCubbin, Scott Dearie, and Gavin Munro, Spirit AeroSystems (Europe) Limited, Prestwick, Scotland, United Kingdom

---Quality and conformance checks can be a serious limitation on production throughput in aerospace manufacturing. Traditionally Non-Destructive Evaluation (NDE) and metrology measurements are undertaken at different stages of a product manufacture cycle using specific dedicated equipment and personnel. However since both processes involve direct interaction with the component's surface, an opportunity exists to combine these to potentially reduce overall cycle time. In addition when considering moves towards automation of both inspection processes, it is clear that measured metrology data is an essential input parameter to the automated NDE workflow. The authors present the findings of a proof of concept combined sub scale NDE and Metrology demonstrator cell for aerospace components. Permitting a maximum part area size of 3 x 1 m, KUKA KR5 6 degree of freedom robotic manipulators were utilized to deploy two inspection payloads. Firstly automated non-contact photogrammetric metrology measurement was employed to inspect the structure for conformance of dimension in relation to reference designs (available from CAD). Secondly automated phased array technology was deployed to inspect and produce ultrasonic thickness mapping of components of nominal 20mm thickness. Parameters such as overall cycle time, part dimensional accuracy, robotic path accuracy and data registration are assessed in the paper to highlight both the current state of the art performance available and the future direction of required research focus.

3:50 PM

Automated Full Matrix Capture for Industrial Processes
---**Roy H. Brown**, S. Gareth Pierce, Jerzy Dziewierz, Joseph Jackson, Timothy Lardner, Charles MacLeod, and Maxim Morozov, University of Strathclyde, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; Ian Collison, Rolls-Royce plc, Derby, United Kingdom; Ben Dutton, Manufacturing Technology Centre Ltd., Coventry, United Kingdom

---Full matrix capture (FMC) ultrasound can be used to generate a permanent re-focusable record of data describing the geometry of a part; a valuable asset for an inspection process. FMC is a desirable acquisition mode for automated scanning of complex geometries, as it allows compensation for surface shape in post processing and application of the total focusing method. However, automating the delivery of such FMC inspection remains a significant challenge for real industrial processes due to the high data overhead associated with the ultrasonic acquisition. The benefits of performing non-destructive evaluation using six-axis industrial robots are well versed when considering complex inspection geometries, but such an approach brings additional challenges to scanning speed and positional accuracy when combined with FMC inspection. This study outlines steps taken to optimize the scanning speed and data management required to scan a diffusion bonded test plate from Rolls-Royce. A system combining a robotic arm and a reconfigurable FMC phased array controller is presented. The speed and data implications of different scanning methods are compared, and the impacts on data visualization quality are discussed with reference to this study. For the 0.5 square meter sample considered, typical acquisitions of 18 terabytes per square meter were measured for a triple back wall FMC acquisition, illustrating the challenge of combining high data throughput with acceptable scanning speeds. This work was funded jointly by EPSRC and Rolls-Royce plc as part of RCNDE core research, and was carried out in partnership with the Manufacturing Technology Centre as part of the UK's High Value Manufacturing Catapult.

4:10 PM

Robotic Path Planning for Non-Destructive Testing of Complex Shaped Surfaces
---**Carmelo Mineo** and Stephen G. Pierce, University of Strathclyde, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; Pascual I. Nicholson and Ian Cooper, TWI, Technology Centre Wales, Port Talbot, United Kingdom

---The requirement to increase inspection speeds for non-destructive testing (NDT) of composite aerospace parts is common to many manufacturers. The prevalence of complex curved surfaces in the industry provides significant motivation for the use of 6 axis robots for deployment of NDT probes in these inspections. A new system for robot deployed the ultrasonic inspection of composite aerospace components is presented. The key novelty of the approach is through the accommodation of flexible robotic trajectory planning, co-ordinated with the NDT data acquisition. Using a flexible approach in MATLAB, the authors have developed a high level custom toolbox that utilizes external control of an industrial 6 axis manipulator to achieve complex path planning and provide synchronization to the employed ultrasonic phase array inspection system. The developed software maintains a high level approach to the robot programming, in order to ease the programming complexity for an NDT inspection operator. Crucially the approach provides a pathway for a conditional programming approach and the capability for multiple robot control (a significant limitation in many current off-line programming applications). Ultrasonic and experimental data has been collected for the validation of the inspection technique. The path trajectory generation for a large, curved carbon-fibre-reinforced polymer (CFRP) aerofoil component has been proven and is presented. The path error relative to a raster-scan tool-path, suitable to ultrasonic phased array inspection, has been measured to be within ± 2mm over the 1.6 m2 area of the component surface.

4:30 PM

The Computational Enhancement of Automated Non-Destructive Inspection
---**Nicholas Brierley**, Trevor Tippetts, and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

---Automated NDE is of increasing industrial importance, but the large associated data volumes make the effective detection of defect signals particularly challenging. The collected data typically include signals describing several interrogations of a given sample region, be it within a single data channel, across multiple channels or over the course of repeated inspections. The systematic combination of these diverse readings is recognized to provide a means to improve the reliability of the inspection, for example by enabling noise suppression. Specifically, such data fusion makes it possible to declare regions of the component defect-free to a very high probability whilst readily identifying indications. This paper offers a review of the software-based data fusion framework developed to that end. This system has been shown to allow the false call rate to be reduced by orders of magnitude for a given high probability of detection compared with a conventional detection approach. Results are presented from the two industrial applications focused on in development, a mid-manufacture aerospace turbine disk inspection and an in-service power station turbine rotor inspection. Additionally, relevant alternative applications are considered and future opportunities discussed.

4:50 PM

Development of RFECT System for ILI Robot of 16 Inch Unpiggable Gas Pipeline
---**Jaeha Park**, Joengwon Park, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Mechanical Engineering, Suwon, Gyeonggi-do, South Korea; Huiryong Yoo, Sungho Cho, and Yongwoo Rho, Korea Gas Corporation, R&D Division, Incheon, South Korea

---In this paper, a RFECT (Remote Field Eddy Current Technique) system for ILI (In-line Inspection) robot to inspect flaws in the 16 inch gas pipelines was developed. The RFECT system is ideal for unpiggable gas pipelines because components of the system can be made much smaller than the diameter of the pipe to be inspected. The RFECT system has no drag force compare to the MFL (Magnetic Flux Density) system used for conventional ILI of pipelines. Thus, RFECT system can be efficiently integrated to robot platform for driving inside the pipelines. In this work, we will describe a detailed structure of the developed RFECT system and show the experimental results to verify its performance.

Session 32

Thursday, July 24, 2014

SESSION 32
NONLINEAR
Cliff J. Lissenden, Chairperson
Salmon-Snake

3:30 PM **Characterization of Material Degradation in Pipes Using Nonlinear Guided Wave**
---**Yang Liu**, Cliff J. Lissenden, and Joseph L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

3:50 PM **Stress Measurements in Thick Plates Using Nonlinear Ultrasonics**
---**Z. Abbasi** and D. Ozevin, University of Illinois at Chicago, Civil and Materials Engineering, Chicago, IL 60607

4:10 PM **Effect of Localized Microstructural Evolution on Higher Harmonic Generation of Guided Wave Modes**
---**Gloria Choi**, Yang Liu, and Cliff Lissenden, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

4:30 PM **Experimental Verification of Multi-Mode Nonlinear Resonance Ultrasound Spectroscopy to Localize Closed Cracks**
---**Yoshikazu Ohara**, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan; Brian E. Anderson, T. J. Ulrich, Pierre-Yves Le Bas, and Paul A. Johnson, Los Alamos National Laboratory, Earth and Environmental Sciences, Los Alamos, NM 87545; Sylvain Haupert, Laboratoire d'imagerie Parametrique, UPMC Paris 6, CNRS UMR 7623, Paris, France

4:50 PM **Numerical Study of Material Nonlinearity Assessment Based on Non-collinear Ultrasonic Wave Mixing**
---**Ziyin Zhang** and Peter B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, Ohio 45221; Waled Hassan, Rolls-Royce Corporation, Indianapolis, IN 46225

3:30 PM

Characterization of Material Degradation in Pipes Using Nonlinear Guided Wave
---**Yang Liu**, Cliff J. Lissenden, and Joseph L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

---Cylindrical waveguides such as pipelines, pressure vessels, and heat exchangers are widely used in many industries for the transportation and storage of oil, gas, chemicals and other products. The work environment for these structures could be severe, i.e. high temperature and highly radioactive for nuclear heat exchanger, and high pressure for many pressure vessels, etc. The presence of damage in these structures can have catastrophic consequences. Thus, there is a strong need for NDE/SHM technology that is capable of detecting precursors to macro scale damage in order to provide early warning. As a finite amplitude monochromatic wave propagates through a weakly nonlinear material, higher harmonics are generated due to the wave distortion associated with lattice anharmonicity. The generation of measurable higher harmonics is extremely useful because these harmonics are sensitive to the micro-structural features that precede the occurrence of macroscale damage. In this work the characteristics of higher order harmonic generation of flexural modes is investigated. The problem is modeled in a generalized fashion in that interaction of two propagating waves is considered along with arbitrary order nonlinearity and harmonics. The criteria for internal resonance, synchronism and nonzero power flux from the primary mode to a secondary mode, are determined. A circumferential order relationship is derived that ensures nonzero power flux transfer. In the special case of second harmonic generation, the relations for flexural modes are shown to reduce to those of axisymmetric modes in the limit of axisymmetric wave propagation. A physical interpretation of flexural modes is provided that enables activation of a single dominant flexural mode. This interpretation enables preselection of a primary mode that generates an internally resonant secondary mode.

3:50 PM

Stress Measurements in Thick Plates Using Nonlinear Ultrasonics
---**Z. Abbasi** and D. Ozevin, University of Illinois at Chicago, Civil and Materials Engineering, Chicago, IL 60607

---In this paper the interaction between nonlinear ultrasonic characteristics and stress state of complex loaded thick steel plates using fundamental theory of nonlinear ultrasonics is investigated in order to measure the stress state at a given cross section. The measurement concept is based on phased array placement of ultrasonic transmitter-receiver to scan three angles of a given cross section using Rayleigh waves. The change in the ultrasonic data in thick steel plates is influenced by normal and shear stresses; therefore, three measurements are needed to solve the equations simultaneously. Different thickness plates are studied in order to understand the interaction of Rayleigh wave penetration depth and shear stress. The purpose is that as the thickness becomes smaller, the shear stress becomes negligible at the angled measurement. For thicker cross section, shear stress becomes influential if the depth of penetration of Rayleigh wave is greater than the half of the thickness. The influences of plate thickness and ultrasonic frequency on the identification of stress tensor are numerically studied in 3D structural geometry and Murnaghan material model. The experimental component of this study includes uniaxial loading of the plate while measuring ultrasonic wave at three directions (perpendicular, parallel and angled to the loading direction). Instead of rotating transmitter-receiver pair for each test, a device capable of measuring the three angles is designed and implemented in the experiments. Finally, the numerical results are compared with the experimental results.

4:10 PM

Effect of Localized Microstructural Evolution on Higher Harmonic Generation of Guided Wave Modes

---**Gloria Choi**, Yang Liu, and Cliff Lissenden, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

---Higher harmonic generation of ultrasonic waves have the potential to be used to detect precursors to macroscale damage of phenomenon like fatigue due to microstructural evolution contributing to nonlinear material behavior. Primary-secondary mode pairs can be selected to meet the internal resonance criteria, i.e., synchronization and nonzero power flux, in order to generate a cumulative secondary wave field. A cumulative secondary wave field is highly desirable in experiments because it enables material nonlinearities to be distinguished from other sources of nonlinearity, such as the measurement system. Since damage accumulation is often localized, this research investigates the localization of plastic deformation. Aluminum plates having different plastic zone sizes were plastically deformed to different levels. The fundamental shear horizontal mode was then generated in the plate samples by a magnetostrictive transducer. After propagating through the plastic zone the primary wave mode and its third harmonic were received by a second transducer. The results indicate that third harmonic generation is proportional to the size of the plastic zone as well as to the magnitude of the plastic strain. Results of a parallel numerical study using the S1-S2 Lamb mode pair are described within the context of the experimental results.

4:30 PM

Experimental Verification of Multi-Mode Nonlinear Resonance Ultrasound Spectroscopy to Localize Closed Cracks

---**Yoshikazu Ohara**, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan; Brian E. Anderson, T. J. Ulrich, Pierre-Yves Le Bas, and Paul A. Johnson, Los Alamos National Laboratory, Earth and Environmental Sciences, Los Alamos, NM; Sylvain Haupert, Laboratoire d'imagerie Parametrique, UPMC Paris 6, CNRS UMR 7623, Paris, France

---Nonlinear resonance ultrasound spectroscopy (NRUS) has been widely used to quantify the global nonlinearity of a sample by measuring the amplitude dependence of resonance frequencies. As an extension, multi-mode NRUS has been proposed to localize damage, and has been verified in a one-dimensional (1D) simulation [K. V. D. Abeele, et al., JASA, 122(2007)73]. The objective of this study is to experimentally demonstrate the fundamental concept of multi-mode NRUS. The transmitter was a piezoelectric disc bonded to the sample. The receiver was a scanning laser vibrometer. In the experiment, the first several vibration modes were measured. To prove the concept, appropriate vibration modes were selected. Then the input-amplitude dependence of the resonance frequency was measured for each mode. As a result, no peak shift was observed with the increase in the input amplitude for resonance modes possessing a strain node at the crack location. In contrast, a peak shift was obviously observed for the resonance modes possessing a strain anti-node at the crack location. The crack's location is therefore identified at the location of the strain anti-node. Thus, the concept of multi-mode NRUS was experimentally verified. As a further extension of multi-mode NRUS, we focused on the generation of nonlinear frequency components. As a result, not only higher harmonics but also self-modulation components were clearly identified for the mode with a strain anti-node at the crack location. Moreover, by exciting the specimen with larger input, the generation and threshold behavior of subharmonic and ultraharmonic components were clearly observed. Thus, we found that the above nonlinear components can be useful indicators of multi-mode NRUS in localizing closed cracks.

4:50 PM

Numerical Study of Material Nonlinearity Assessment Based on Non-collinear Ultrasonic Wave Mixing

---**Ziyin Zhang** and Peter B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, Ohio 45221; Waled Hassan, Rolls-Royce Corporation, Indianapolis, IN 46225

---Recent research has indicated that non-collinear ultrasonic wave mixing can be exploited for the measurement of both bulk material nonlinearity and localized interface nonlinearity. In the particular configuration considered in this study, two oblique shear waves are mixed to generate a third longitudinal wave as a result of nonlinear interaction with the material. First, it was numerically verified that, in agreement with the original analytical predictions of Taylor and Rollins in 1964, the only nonlinear material parameter that affects the strength of the mixed longitudinal wave is the second Murnaghan coefficient (m). In sharp contrast with the nonlinearity parameter (β) measured with conventional longitudinal wave harmonic generation, the mixed signal is of purely material origin and does not depend on the geometrical nonlinearity of the displacement-strain relationship. Second, a simple analytical approximation was developed to determine the amplitude of the mixed signal. This approximation was found in good agreement with both computational simulations and experimental results. Third, it was shown that in the presence of a perfectly reflecting interface the bulk nonlinearity decreases due to the complex linear reflection coefficient of such an interface above the longitudinal critical angle. Finally, the excess nonlinearity produced by an imperfect nonlinear interface was also considered. It was found that a nonlinear interface produces an additional symmetric nonlinear signal that is the same for both the reflected and transmitted fields. This excess nonlinearity can be exploited to characterize the imperfect interface, especially from the reflected part of the mixed signal that is essentially free of bulk nonlinearity contribution from the surrounding host material.

FRIDAY

FRIDAY, JULY 25, 2014

	Session 33 **Composites III** ***Cottonwoods-Firs***	**Session 34** **Benchmark** ***Pines***	**Session 35** **UT Measurements** ***Willows***	**Session 36** **Eddy Current** ***Salmon-Snake***
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Session 33

Friday, July 25, 2014

SESSION 33
COMPOSITES III
Mahmood Haq and Gerges Dib, Co-Chairpersons
Cottonwoods-Firs

8:30 AM **Comparison of Results from Different NDE Techniques from Ceramic Matrix Composites with Varying Porosity Levels**
---I. Smyth[1], **G. Ojard**[2], U. Santhosh,[3] J. Ahmad[3], and Y. Gowayed[4], [1]Pratt & Whitney, East Hartford, CT 06118; [2]United Technologies Research Center, East Hartford, CT 06118; [3]Structural Analytics, Inc., Carlsbad, CA 92013; [4]Auburn University, Auburn, AL 36849

8:50 AM **Nondestructive Evaluation Techniques for Development and Characterization of Carbon Nanotube Based SuperStructures**
---**Russell A. Wincheski**, Phillip A. Williams, and Emilie J. Siochi, NASA Langley Research Center, Research Directorate, Hampton, VA 23681; Jae-Woo Kim and Godfrey Sauti, National Institute of Aerospace, Hampton, VA 23681

9:10 AM **Thermo-Oxidative Degradation Assessment in Quasi-Isotropic Carbon Fiber/Epoxy Composites**
---**Connor Daily** and Nicola Bowler, Iowa State University, Materials Science and Engineering, Ames, IA, 50011; Dan J. Barnard and Nicola Bowler, Iowa State University, Center for NDE, Ames, IA, 50011; Roger W. Jones and John F. McClelland, Iowa State University, Biochemistry, Biophysics, and Molecular Biology, Ames, IA, 50011; Nicola Bowler, Iowa State University, Electrical and Computer Engineering , Ames, IA, 50011

9:30 AM **Complementary Matrix and Fibre Structure Defects Analysis on Composites by Combined Application of Acoustic Microscopy and High-Frequency Eddy-Current Testing**
---**Michael Hertl** and Takumi Aida, Insight k.k., 2-6-7 Hyakunincho, Shinjuku-ku, Tokyo 169-0073, Japan; Richard Kupke, Suragus GmbH, Maria-Reiche-Str. 1, 01109 Dresden, Germany; Nicolas Paillet, Predictive Image S.A.S., 193 Chassolières, 38340 Voreppe, France

9:50 AM **A Multi-Inspection Non-Destructive Testing Method for Joint Composite Component Tensile Property and Quality Evaluation**
---**Weihan Wang**, Jingjing He, Weifang Zhang, and Shengwang Liu, Beihang University, Science and Technology on Reliability and Environment Engineering Laboratory, Beijing, China

10:10 AM **Lamb Wave Dispersion and Anisotropy Profiling of Composite Plates via Non-Contact Air-Coupled and Laser Ultrasound**
---**Mohammad S. Harb**, North Carolina State University, Raleigh, NC 27695; Fuh Gwo Yuan, National Institute of Aerospace, Hampton, VA 23666

10:30 AM ***Adjourn***

8:30 AM

Comparison of Results from Different NDE Techniques from Ceramic Matrix Composites with Varying Porosity Levels

---I. Smyth[1], **G. Ojard**[2], U. Santhosh,[3] J. Ahmad[3], and Y. Gowayed[4], [1]Pratt & Whitney, East Hartford, CT 06118; [2]United Technologies Research Center, East Hartford, CT 06118; [3]Structural Analytics, Inc., Carlsbad, CA 92013; [4]Auburn University, Auburn, AL36849

---Ceramic matrix composites (CMC's) are attractive materials for use in advanced turbine engines. Due to the nature of available processing techniques, however, the amount and distribution of porosity in CMC's can vary greatly. This can be particularly true in parts with complex geometries. It is therefore important to characterize the porosity with non-destructive techniques and understand its effect on properties. A series of CMC samples were fabricated with varying levels of porosity and analyzed with different NDE techniques. The results were categorized and analyzed with respect to ease of interpretation and degree to which they could be quantified and used in models to determine the effects of defects. The results were also correlated with microstructural examination and mechanical properties.

8:50 AM

Nondestructive Evaluation Techniques for Development and Characterization of Carbon Nanotube Based SuperStructures

---**Russell A. Wincheski**, Phillip A. Williams, and Emilie J. Siochi, NASA Langley Research Center, Research Directorate, Hampton, VA 23681; Jae-Woo Kim and Godfrey Sauti, National Institute of Aerospace, Hampton, VA 23681

---Recently, multiple commercial vendors have developed capability for the production of large-scale quantities of high quality carbon nanotube sheets and yarns. While the materials have found use in electrical shielding applications, development of structural systems composed of a high volume fraction of carbon nanotubes is still lacking [1,2]. A recent NASA program seeks to address this by prototyping a structural nanotube composite with strength to weight ratio exceeding current state of the art carbon fiber composites. Commercially available carbon nanotube sheets, tapes, and yarns are being processed into high volume fraction carbon nanotube-polymer nanocomposites. Nondestructive evaluation techniques have been applied throughout this development effort for material characterization and process control. This paper will report on the progress of these efforts, including magnetic characterization of residual catalyst content, Raman Scattering characterization of nanotube diameter, defect ratio, and nanotube strain, and Polarized Raman Scattering for characterization of nanotube alignment.

References:

1. Chou, T.-W., et al. (2010). "An assessment of the science and technology of carbon nanotube-based fibers and composites." Composites Science and Technology 70(1): 1-19.
2. De Volder, M. F. L., et al. (2013). "Carbon Nanotubes: Present and Future Commercial Applications." Science 339(6119): 535-539.

9:10 AM

Thermo-Oxidative Degradation Assessment in Quasi-Isotropic Carbon Fiber/Epoxy Composites

---**Connor Daily** and Nicola Bowler, Iowa State University, Materials Science and Engineering, Ames, IA 50011; Dan J. Barnard and Nicola Bowler, Iowa State University, Center for NDE, Ames, IA 50011; Roger W. Jones and John F. McClelland, Iowa State University, Biochemistry, Biophysics, and Molecular Biology, Ames, IA 50011; Nicola Bowler, Iowa State University, Electrical and Computer Engineering , Ames, IA 50011

---Components made from polymer matrix composites (PMCs) are finding increasing use in armored vehicles for the purpose of weight savings and fuel efficiency. Often times, these PMC components are installed next to engines, or in other high-temperature environments within the vehicle. The present work investigates the change in surface chemistry and its correlation with changes in the interlaminar shear strength (ILSS) due to accelerated thermo-oxidative ageing of a quasi-isotropic carbon fiber reinforced epoxy laminate. Samples are aged isothermally at various temperatures whose selection is guided by degradation steps revealed by thermo-gravimetric analysis. Fourier transform infrared (FTIR) photoacoustic spectroscopy is utilized to identify the chemical changes due to ageing, and compression-test results reveal a non-linear decrease in ILSS with increasing ageing temperature. A correlation between the FTIR and ILSS data sets suggests that nondestructive FTIR techniques may be used for assessing ILSS of PMCs.---This material is based on work supported the Army Research Laboratory as part of cooperative agreement number W911NF0820036 at the Center for Nondestructive Evaluation at Iowa State University.

9:30 AM

Complementary Matrix and Fibre Structure Defects Analysis on Composites by Combined Application of Acoustic Microscopy and High-Frequency Eddy-Current Testing

---**Michael Hertl** and Takumi Aida, Insight k.k., 2-6-7 Hyakunincho, Shinjuku-ku, Tokyo 169-0073, Japan; Richard Kupke, Suragus GmbH, Maria-Reiche-Str. 1, 01109 Dresden, Germany; Nicolas Paillet, Predictive Image S.A.S., 193 Chassolières, 38340 Voreppe, France

---Acoustic microscopy is a well-known non-destructive analysis technology with a wide application range in particular in the aeronautics field. It has an excellent capability for identifying cracks in aluminum or any other metal. Since the onset of massive use of composites in modern airplane construction, acoustic microscopy is the ideal tool for detecting pores and delaminations in carbon fiber reinforced plastics (CFRP). However, the most critical aspect for mechanical stability of CFRP's concerns the structure of the carbon fibers themselves, which is very difficult to analyze in detail with acoustic microscopy. Recently, High-Frequency Eddy Current technology has been introduced for the visualization of the carbon fiber structure in both raw materials and within final CFRP composite samples. This technology allows to identify failures like wrinkles, misalignments, gaps, or missing rowings even in hidden layers of multilayer CFRP's (1). In the present study we conduct both acoustic microscopy and High-Frequency Eddy Current experiments on a set of CFRP samples as typically used in the aeronautics industry. The differences in the failure detection capabilities of both technologies will be shown. In particular, it will be demonstrated that both technologies are complementary in the sens that acoustic microscopy still is the most relevant tool for matrix defect analysis, whereas Eddy Current testing appears to be an excellent new way for the characterization of the fiber structure itself, even in hidden inner layers of final CFRP components.

Reference:

1. H. Heuer et al.: Testing of CFRP using High-Frequency Eddy Current Techniques, Proceedings of the 18th WCNDT, 16-20 April 2012, Durban, South Africa.

9:50 AM

A Multi-Inspection Non-Destructive Testing Method for Joint Composite Component Tensile Property and Quality Evaluation

---**Weihan Wang**, Jingjing He, Weifang Zhang, and Shengwang Liu, Beihang University, Science and Technology on Reliability and Environment Engineering Laboratory, Beijing, China

---Carbon fiber composites have excellent mechanical properties, which are widely used in aerospace industry.However, 60% to 80% damage in composite occurs in joint components. This research focus on two major method used in mechanical joint: pressing rivet connection and pulling rivet connection. This study presents a systematic method and procedure for joint composite component tensile property and quality evaluation. The quality evaluation is performed based on tensile test and two non-destructive testings (ultrasound test and X-ray test).The tensile test show that the mean tensile stress of pulling rivet is 160.21Mpa, which is higher than that of pressing rivet (94.48Mpa).The ultrasound and X-ray test results show that the rivet and plate is an interference fit in the pulling rivet connection, which makes the composite plate firmly fixed. However, the fix is weak in the pressing rivet connection, due to the small gap between the rivet and plate. The results show that the pulling rivet connection has higher tensile strength compare with pressing rivet connection and it is more suitable for the main bearing structure of aircraft. On the other hand, the pressing rivet is suitable for the secondary bearing structure of aircraft.

10:10 AM

Lamb Wave Dispersion and Anisotropy Profiling of Composite Plates via Non-Contact Air-Coupled and Laser Ultrasound

---**Mohammad S. Harb**, North Carolina State University, Raleigh, NC 27695; Fuh Gwo Yuan, National Institute of Aerospace, Hampton, VA 23666

---Conventional ultrasound inspection has been a standard non-destructive testing method for providing an in-service evaluation and noninvasive means of probing the interior of a structure. In particular, measurement of the propagation characteristics of Lamb waves allows inspection of plates that are typical components in aerospace industry. A rapid, complete non-contact approach for excitation and detection of Lamb waves is presented and applied for non-destructive evaluation of composites. An air-coupled transducer excites ultrasonic waves on the surface of a composite plate, generating different propagating Lamb wave modes and a laser Doppler vibrometer (LDV) is used to measure the out-of-plane velocity of the plate. This technology, based on direct waveform imaging, focuses on measuring dispersive curves for A0 mode in a CFRP composite laminate and its anisotropy. A Two-dimensional Fourier transform (2D-FFT) is applied to out-of-plane velocity data captured experimentally using LDV to go from the time-spatial domain to frequency-wavenumber domain. The result is a 2D array of amplitudes at discrete frequencies and wavenumbers for A0 mode in a given propagation direction along the composite. The peak values of the curve are then used to construct the phase velocity dispersion curve, which can be also obtained directly using Snell's law and the incident angle of the excited ultrasonic waves. A higher resolution and strong correlation between numerical and experimental results are observed for dispersive curves with Snell's law method in comparison to 2D-FFT method. Phase velocity and group velocity dispersion curves for the composite plate along different directions of wave propagation are measured. The visual read-out of the dispersion curves at different propagation directions provides profiling and measurements of the composite anisotropy. The results proved a high sensitivity of the air-coupled and laser ultrasound technique in non-contact characterization of Lamb wave dispersion and material anisotropy of composite plates.

Session 34

SESSION 34
BENCHMARK
Joseph N. Gray, Chairperson
Pines

8:30 AM	**Simulation of ECT Inspection Using Magnetic Sensors: Solution to the WFNDEC 2014 Eddy Current Benchmark Problem** ---**C. Reboud** and R. Miorelli, CEA, LIST, Département Imagerie Simulation pour le Contrôle, 91191 Gif-sur-Yvette, France; C. Voulgaraki and T. Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Bakola & Salviera, Kozani 50100, Greece; N. Poulakis, Technological Educational Institute of Western Macedonia, Department of Electrical Engineering, Koila, 50100, Greece
8:50 AM	**Numerical Tools for Eddy Current Testing Simulations** ---**Cesar G. Camerini**, João Vicente G. Rocha, João Marcos A. Rebello, and Gabriela R. Pereira, Laboratory of Nondestructive Testing, Corrosion and Welding, Federal University of Rio de Janeiro, Dept. of Metallurgical and Materials Engineering, Rio de Janeiro, Brazil
9:10 AM	**Radiography Benchmark 2014** ---**Gerd-Rüdiger Jaenisch**, Andreas Deresch, and Carsten Bellon, BAM Federal Institute for Materials Research and Testing, Division 8.3 Radiological Methods, Berlin, Germany; Andreas Schumm, Flora Lucet-Sanchez, and Pierre Guerin, EDF R&D, 1 avenue du Général de Gaulle, 92141 Clamart, France
9:30 AM	**Development of General X-Ray Scattering Model** ---**Joe Gray** and Scott Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011
9:50 AM	**Solution of the FMC-TFM Ultrasonic Benchmark Problem Using CIVA** ---Sébastien Robert, Philippe Bredif, Pierre Calmon, Guillaume Daniel, and **François Cartier**, CEA LIST, NDT Department, France
10:10 AM	**A Proposed Benchmark for Simulation in Radiographic Testing** ---**D. Tisseur**[1], M. Costin[1], B. Rattoni[1], and A. Vabre[1], [1]CEA LIST, CEA Saclay 91191 Gif sur Yvette Cedex, France
10:30 AM	***Adjourn***

8:30 AM

Simulation of ECT Inspection Using Magnetic Sensors: Solution to the WFNDEC 2014 Eddy Current Benchmark Problem
---**C. Reboud** and R. Miorelli, CEA, LIST, Département Imagerie Simulation pour le Contrôle, 91191 Gif-sur-Yvette, France; C. Voulgaraki and T. Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Bakola & Salviera, Kozani 50100, Greece; N. Poulakis, Technological Educational Institute of Western Macedonia, Department of Electrical Engineering, Koila, 50100, Greece

---The use of magnetic sensors, such as Hall sensors or GMRs, is attracting a lot of interest in some applications of eddy current testing (ECT) [1,2,3]. Used at high frequencies (with respect to ECT applications, that is around f = 1 MHz), their small size enables the setup of high resolution matrix probes. Used a lower ones, their constant sensitivity with frequency makes them, at some point, more interesting than coils for the detection of buried flaws or the inspection of ferromagnetic materials. This communication addresses the 2014 WFNDEC ECT benchmark, providing reference experimental data in configurations of plate inspection with a probe, made of an emitting coil and a receiving Hall sensor. From the modelling point of view, if we consider that the magnetic receiver does not, itself, locally perturb the magnetic field, the ECT signal to compute is proportional to the projection of the magnetic field measured by the magnetic sensor, onto its direction of sensitivity. The proposed method of simulation is based on a semi-analytical integral method [4], describing the flaw as a secondary source. Analytical expressions of Green operators, verifying suitable conditions at the piece interfaces, as well as radiation conditions at infinity are applied to calculate the effect of this fictitious source, which effect cancels out the eddy currents component collinear with the flaw opening. After the resolution of the integral equation describing the interaction between the flaw and the induced eddy current density, the ECT signal is derived using a reciprocity argument, considering the receiver as a very small loop of current. This equivalent description yields a large improvement of the calculation efficiency. Comparisons with benchmark data show the accuracy of the model, which performance and perspectives of improvement are then discussed.

References:

1. G. Yang, Z. Zeng, Y. Deng, X. Liu, L. Udpa, A. Tamburrino, S.S. Udpa, 3D EC-GMR sensor system for detection of subsurface defects at steel fastener sites, NDT & E International, Volume 50, September 2012, Pages 20-28, ISSN 0963-8695, http://dx.doi.org/10.1016/j.ndteint.2012.04.007.
2. Development of flexible array eddy current probes for complex geometries and inspection of magnetic parts using magnetic sensors, Marchand, B. and Decitre, J.-M. and Sergeeva-Chollet, N. and Skarlatos, A., AIP Conference Proceedings, 1511, 488-493 (2013), http://dx.doi.org/10.1063/1.4789087.
3. Voulgaraki, C.; Poulakis, N.; Theodoulidis, T., "Theoretical Simulations and Quantitative Magnetic Field Measurements for Eddy-Current Testing with an HTS SQUID System," Applied Superconductivity, IEEE Transactions on , vol.23, no.4, pp.1603012,1603012, Aug. 2013. http://dx.doi.org/10.1109/TASC.2013.2256357.
4. R. Miorelli; C. Reboud; D. Lesselier; T. Theodoulidis, Eddy Current Modeling of Narrow Cracks in Planar-Layered Metal Structures, IEEE Transactions on Magnetics, vol. 48, no. 10, pp. 2551-2559, Oct. 2012. http://dx.doi.org/10.1109/TMAG.2012.2197403.

8:50 AM

Numerical Tools for Eddy Current Testing Simulations
---**Cesar G. Camerini**, João Vicente G. Rocha, João Marcos A. Rebello, and Gabriela R. Pereira, Laboratory of Nondestructive Testing, Corrosion and Welding, Federal University of Rio de Janeiro, Dept. of Metallurgical and Materials Engineering, Rio de Janeiro, Brazil

---Computer simulation is becoming increasingly important for Non Destructive Testing (NDT). The main NDT techniques have dedicated software to numerically reproduce experimental tests. In case of Eddy Current Testing (ECT) several commercial FEM packages are available. However, a reliable and consistent simulation result depends on many parameters defined by the user, such as: mesh type and refinement, current density definition, coil impedance calculation method. Taking the impedance calculation as an example, it can be calculated by many different methods in the model. Nevertheless, the method selected by the user may interfere results accuracy. Equation 1 shows the conventional way to calculate the coil impedance, where the real part is computed with the Joule Losses (L) in the conductive region, and the imaginary part is calculated by the magnetic energy density (Wm) in the whole solution domain. The equation 2 shows a different method to calculate the impedance integrating only the eddy current coil volume. This second approach is more accurate since it does not involve integration over regions far from the coil, as in equation 1. Other solutions such as Ohm’s law calculation can be also performed but different input parameters must be considered in the model.

$$Z = R + j\omega L = \frac{1}{I^2}(L + j\omega 2Wm) \qquad (1)$$

$$Z = \frac{1}{I^2}\int_{coil} E.JdV = \frac{j\omega}{I^2}\int_{coil} A.JdV \qquad (2)$$

In the current work some numerical tools (such as impedance calculation methods) and good practice hints (mesh refinement, narrow cracks modeling) are presented to assist an ECT simulation. A few ECT benchmark problems were solved from different approaches and the accuracy of each solution was compared. Comments of the advantages and disadvantages of using such numerical tools are made.

9:10 AM

Radiography Benchmark 2014

---**Gerd-Rüdiger Jaenisch**, Andreas Deresch, and Carsten Bellon, BAM Federal Institute for Materials Research and Testing, Division 8.3 Radiological Methods, Berlin, Germany; Andreas Schumm, Flora Lucet-Sanchez, and Pierre Guerin, EDF R&D, 1 avenue du Général de Gaulle, 92141 Clamart, France

---The purpose of the 2014 WFNDEC RT benchmark study was to compare predictions of various models of radiographic techniques, in particular those that predict the contribution of scattered radiation. All calculations were carried out for homogenous materials and a mono-energetic X-ray point source in the energy range between 100 keV and 10 MeV. The calculations were to include the best physics approach available considering electron binding effects. Secondary effects like X-ray fluorescence and bremsstrahlung production were to be taken into account if possible. The problem to be considered had two parts. Part I examined the spectrum and the spatial distribution of radiation behind a single iron plate. Part II considered two equally sized plates made of iron and aluminum respectively, only evaluating the spatial distribution. Here we present the results of above benchmark study, comparing them to MCNP as assumed reference model. The possible origins of the observed deviations are discussed.

9:30 AM

Development of General X-Ray Scattering Model
---**Joe Gray** and Scott Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---X-ray scattering is a complex process made difficult to describe due to the effects of a complex energy spectrum interacting with a wide range of material types in complex geometry. The scattering is further complicated by the volume of material illuminated and the experimental configuration of the data acquisition. The importance of accounting for the key physics in scattering modeling is critical to the viability of the model. For example, scattering in the detector and the speed of the detector, as measured by the absorbed dose needed to produce a signal, are important capturing undercut effects. The noise properties of the detectors are affected by the photon energy. We report on a semi-empirical treatment of x-ray scattering that includes a full energy treatment for a wide range of material types. We also include complex geometry effects that the part shape introduces. The treatment is based on experimental measurements using an energy dispersive germanium detector over energies from 20kEv to 320keV. Detector stripping routines for detector artifacts were developed. This treatment is showing good results with experimental measurements of the scattering component agreeing with the model results to the 10% level over the range of x-ray energies and materials typical in industrial applications. Computation times for this model are in the range of a few minutes on a typical PC.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

9:50 AM

Solution of the FMC-TFM Ultrasonic Benchmark Problem Using CIVA
---Sébastien Robert, Philippe Bredif, Pierre Calmon, Guillaume Daniel, and **François Cartier**, CEA LIST, NDT Department, France

---The last decade has seen the emergence of new ultrasonic array techniques going beyond the simple application of suitable delays (phased array techniques) for focusing purposes. Amongst these techniques, the particular method combining the so-called FMC (Full Matrix Capture) acquisition scheme with the synthetic focusing algorithm denoted by TFM (Total Focusing Method) has become popular in the NDE community. The 2014 WFNDEC ultrasonic benchmark aims at providing FMC experimental data for evaluating the ability of models to predict images obtained by TFM algorithms (or equivalent ones). This data might be used also to compare various imaging algorithms. In this paper we describe the benchmark and report comparisons obtained with the CIVA simulation software. The simulations and measurements are carried out on two steel blocks, one in carbon steel and another in stainless steel. The reference probe is a 64 elements linear array, with .5mm element width and a gap of .1mm, working at 5 MHz. The benchmark problem consists in predicting images of vertical and tilted notches located on plane or inclined backwalls. The notches have different heights and different ligaments. The images can be obtained considering different pathes (direct echoes or corner echoes). For each notch, the full matrice capture (FMC) have been recorded in one unique position with the probe positioned such that than angle between the probe axis and the notche direction corresponds to 45°. The results are calibrated on the response of a 2mm side drilled hole. For each case, TFM images have been reconstructed for both experimental and simulated signals. The models used are those implemented in CIVA based on Kirkhhoff approximation. Comparisons are reported and discussed.

10:10 AM

A Proposed Benchmark For Simulation In Radiographic Testing
---**D. Tisseur**[1], M. Costin[1], B. Rattoni[1], and A. Vabre[1], [1]CEA LIST, CEA Saclay 91191 Gif sur Yvette Cedex, France

---The French Atomic Energy Commission (CEA) has developed for years the CIVA software dedicated to simulation of NDE techniques such as Radiographic Testing (RT). RT modelling is achieved in CIVA using combination of a determinist approach based on ray tracing for transmission beam simulation and a Monte Carlo model for the scattered beam computation. Furthermore, CIVA includes detectors model in particular common x-ray film and a photostimulable phosphor plate. This communication presents the results obtained on the configurations proposed in the 2014 RT modelling benchmark with the RT models implemented in the CIVA software.

Session 35

Friday, July 25, 2014

SESSION 35
UT MEASUREMENTS
Leonard J. Bond, Chairperson
Willows

8:30 AM	**Vision for Innovating NDT Technologies: Matching NDT with Engineering Decisions** ---**Casper Wassink**, Applus RTD, Technological Center, Delftweg 144, 3046NC Rotterdam, The Netherlands
8:50 AM	**Investigation of a Quantitative and Comprehensive Confidence Measure in NDE** ---**Portia Banerjee**, Seyed Safdarnejad, Lalita Udpa, and Satish Udpa, Nondestructive Evaluation Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824
9:10 AM	**Ultrasound Imaging of Stress Corrosion Cracking** ---**Lars Horchens** and Casper Wassink, Applus RTD, Technological Center, Rotterdam, The Netherlands; Harvey Haines, Kiefner & Associates, Inc., Worthington, OH 43085
9:30 AM	**High Frequency Laminated Transducer Combined with a Delayed Excitation Multi-Pulser** ---**Tsuyoshi Mihara**, Graduate School of Engineering, University of Toyama, 3190 Gofuku, Toyama 930-8555, Japan; Goki Konishi, Tetsuo Asakura, University of Toyama, Toyama 930-8555, Japan
9:50 AM	**Modelling Grain-Scattered Ultrasound in Austenitic Stainless Steel Welds: A Hybrid Model** ---**Oliver Nowers**, D. Duxbury, B. Drinkwater, and A. Velichko, University of Bristol, Queen’s Building, University Walk, Bristol BS8 1TR, United Kingdom
10:10 AM	***Adjourn***

8:30 AM

Vision for Innovating NDT Technologies: Matching NDT with Engineering Decisions

---**Casper Wassink**, Applus RTD, Technological Center, Delftweg 144, 3046NC Rotterdam, The Netherlands

---Traditionally, NDT technologies have been developed for testing during construction and more specifically for testing of welds. Increasingly however, these techniques are used for testing in the in-service life-cycle stage of industrial assets. In the context of stricter regulations, NDT methods are not always suitable for finding the answers to the engineering questions that the data is being collected for. This paper will first analyze the gap between current NDT techniques and the accuracy and performance required for modern applications, like wall thickness trending and finding specific types of corrosion. Data from several projects will be used to illustrate the gap. The findings will then be used to create a framework for how NDT technology could be developed towards meeting these requirements. Examples of current research at the Applus RTD Technological Center will be presented to further clarify the framework.

8:50 AM

Investigation of a Quantitative and Comprehensive Confidence Measure in NDE

---**Portia Banerjee**, Seyed Safdarnejad, Lalita Udpa, and Satish Udpa, Nondestructive Evaluation Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---Quantitative assessment of reliability of classification results is critical in detection and characterization of anomalies in any non-destructive evaluation (NDE) application. Particularly in automated data analysis systems, such a measure enables the system to automatically flag indications where operator intervention is required, and reduces maintenance costs and risks. Classification results are affected by inherent ambiguity of defect classes, non-discriminative features, inadequate training samples and poor data quality. Although these sources of uncertainties in classification have been studied, formulating a single measure which quantifies all of them together has not been done to date. Generally, from Bayesian point of view, the posterior probability is considered as a confidence measure. Posterior probability of occurrence of an event is representative of inter-class similarities and intra-class distance and thus, may be used as a measure of inherent ambiguity of classes and discriminative quality of features. However, estimation of posterior probability itself is affected by number of available training samples. In this paper, we develop a framework to incorporate these major sources of uncertainties of classification results in a single quantity. In lieu of the simplistic assumption, we assume that parameters of the distribution of a class are random variables. We utilize bootstrap method to find empirical distribution of parameters of the class conditional densities based on which a distribution of confidence is found. Utilizing this distribution, different interpretations of the confidence measure may be provided. Analytical results show how statistical properties of the confidence distribution depend on number of training samples and quality of features. Initial results of the approach on eddy current data will be presented.

9:10 AM

Ultrasound Imaging of Stress Corrosion Cracking
---**Lars Horchens** and Casper Wassink, Applus RTD, Technological Center, Rotterdam, The Netherlands; Harvey Haines, Kiefner & Associates, Inc., Worthington, OH 43085

---The formation of cracks in a corrosive environment in combination with tensile stresses is known as stress corrosion cracking. This type of degradation mechanism can lead to sudden and rapid failure of a structure. In a colony of cracks, it is desired to determine the position and depth of individual cracks in order to assess the remaining strength of the structure. In the present paper, acoustical imaging using inverse wave field extrapolation is applied to a pipe coupon exhibiting stress corrosion cracking. It is shown that individual cracks in the colony can be identified and sized. Aside from the direct path into the pipe wall, reflections from the inner and outer surface of the sample are used to determine accurately the extent of the surface-breaking cracks within the material. The images obtained during a scan can be stacked together to provide a three-dimensional visualization of the colony of cracks.

9:30 AM

High Frequency Laminated Transducer Combined with a Delayed Excitation Multi-Pulser

---**Tsuyoshi Mihara**, Graduate School of Engineering, University of Toyama, 3190 Gofuku, Toyama 930-8555, Japan; Goki Konishi, Tetsuo Asakura, University of Toyama, Toyama 930-8555, Japan

---We developed the high accurate inspection system of SPACE (Subharmonic Phased Array for Crack Evaluation), and also have improved the conventional SPACE to enhance the amplitude of displacement for incident ultrasound by developing a laminated transducer combed with a delayed excitation multi-pulser. Up to now, we developed 2.5MHz eight-channel laminated transducer for large displacement ultrasound incidence. However, 5MHz laminated transducer was required to combine with the existing our SPACE using the 4MHz commercial array transducer. In this study, we improved the fabrication procedures for high frequency laminated transducer especially using thinner adhesive layers and electrodes. As the results, we developed ultrasonic 5MHz eight-channel laminated transducer for large displacement ultrasound incidence. We combined the developed laminated transducer to the conventional SPACE to investigate the availability of new large displacement SPACE for the inspection of SCC.

9:50 AM

Modelling Grain-Scattered Ultrasound in Austenitic Stainless Steel Welds: A Hybrid Model

---**Oliver Nowers**, D. Duxbury, B. Drinkwater, and A. Velichko, University of Bristol, Queen's Building University Walk, Bristol BS81TR, United Kingdom

---The ultrasonic inspection of austenitic steel welds can be challenging due to their coarse grain structure, characterized by preferentially oriented, elongated grains. The anisotropy of the weld is manifested as both a 'steering' of the beam and the back-scatter of energy due to the macroscopic granular structure of the weld. However, the influence of many fundamental weld properties, such as mean grain size and orientation distribution, on the magnitude of scattered ultrasound is not well understood. A hybrid model has been developed to allow the study of grain-scatter effects in austenitic welds. An efficient 2D Finite Element (FE) method is used to calculate the complete scattering response from a single elliptical austenitic grain of arbitrary length and width as a function of the specific inspection frequency. A grain allocation model of the weld is presented to approximate the characteristic structures observed in austenitic welds and the complete scattering behavior of each grain calculated. This model is incorporated into a semi-analytical framework for a single-element inspection of a typical weld in immersion. Various parametric studies are presented, including analysis of the impact of grain size and orientation on the magnitude of scattered ultrasound. Validation evidence is also presented using an equivalent experimental setup.

Session 36

SESSION 36
EDDY CURRENT
Rachel Edwards, Chair
Salmon-Snake

8:30 AM **Eddy Current Inspection Method for the 3D Mapping of Corrosion Defects in Steel Bridge Members**
---**George V. Minesawa**, Hiroshi Tamura, and Eiichi Sasaki, Tokyo Institute of Technology, Department of Civil Engineering, Tokyo, Japan

8:50 AM **NDT Inspections Exploiting Invariances on Scale Transformations**
---**Helena Geirinhas Ramos**[a], João Paulo Torres[a], Artur Lopes Ribeiro,[a] and João Marcos Rebello[b], [a]Instituto de Telecomunicações, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais,1 1049-001 Lisboa, Portugal; [b]LABOEND/COPPE, Universidade Federal do Rio de Janeiro, Cidade Universitária, Ilha do Fundão, 21945-970 Rio de Janeiro, RJ, Brasil

9:10 AM **Analyzing Dielectrical Properties of Resins and CFRP with High-Frequency Eddy Current Device Technology**
---**Simone Gäbler**, Leibniz Institute of Polymer Research, Department for Composite Materials, Dresden, Germany; Henning Heuer, Fraunhofer Institute for Ceramic Technology and Systems, Department for Sensors and Sensor Systems, Dresden, Germany

9:30 AM **Developments in Near Electrical Resonance Signal Enhancement (NERSE) Eddy-Current Methods**
---**Robert R. Hughes** and Steve M. Dixon, Department of Physics, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

9:50 AM **Influence of Inspection Parameters in Crack Depth Measurements Using Potential Drop Method**
---David Utrata and Darrel A. Enyart, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:10 AM **Determination of Crack Depth in Aluminum Using Eddy Currents and GMR Sensors**
---**Artur L. Ribeiro**, Dário J. Pasadas, Helena G. Ramos, and Tiago J. Rocha, Instituto de Telecomunicações, IST, Universidade de Lisboa, Portugal

10:30 AM ***Adjourn***

8:30 AM

Eddy Current Inspection Method for the 3D Mapping of Corrosion Defects in Steel Bridge Members

---**George V. Minesawa**, Hiroshi Tamura, and Eiichi Sasaki, Tokyo Institute of Technology, Department of Civil Engineering, Tokyo, Japan

---Corrosion affects a large number of bridges, increasing the maintenance cost and reducing load carrying capacity. The quantitative evaluation of corrosion defects is restricted by the difficulties to access the surface and its large spatial variation. A new inspection corrosion system was proposed for the 3D mapping of corrosion in steel bridge members using the Eddy Current (EC) technology. The inspection method using an EC probe sliding above the inspected surface has been proposed and validated through numerical simulation and by actual inspection for the detection of corrosion damage in steel members. The method is applicable on site and it has the advantage of not requiring surface preparation or paint removal. 3D FEM analysis of the inspection target steel member and of the EC probe was performed for assessing the method applicability to the surface defect detectability, for various defect sizes and shapes. Numerical analysis of the proposed EC probe configurations has been performed, for determining suitable probe parameters. Laboratory inspections and the equivalent numerical analysis were performed for corrosion defect evaluation using steel plates with corrosion defects. Finally, EC inspection of steel bridge elements affected by corrosion damaged were performed for validation of the proposed EC inspection procedure.

8:50 AM

NDT Inspections Exploiting Invariances on Scale Transformations
---**Helena Geirinhas Ramos**[a], João Paulo Torres[a], Artur Lopes Ribeiro,[a] and João Marcos Rebello[b], [a]Instituto de Telecomunicações, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais,1 1049-001 Lisboa, Portugal; [b]LABOEND/COPPE, Universidade Federal do Rio de Janeiro, Cidade Universitária, Ilha do Fundão, 21945-970 Rio de Janeiro, RJ, Brasil

---Most materials deteriorate or degrade as they age. It is assumed that most things fail when their degradation reaches a specified threshold. However, the material condition assessment using nondestructive tests is, in most cases, still an open problem, especially when we are faced with situations that are at the limit of the detection capabilities of the commercial equipment currently available. This paper proposes a technique to surpass this problem. It proofs the possibility to inspect a material in a stretched geometry with an eddy current method (ECM) using a formulation of the scale invariance principle theory. In the scale transform domain, the stretch factor of signals can be manipulated in order to compute quantities invariant to changes in that stretch factor. Let's detail the idea by assuming possible scenarios. For example, if the aim is to detect a crack on the surface of a metallic plate by inspecting the material through the opposite surface. We may start by performing measurements at the laboratory with a scaled model to detect a crack with a given length in a plate of the same material having a thickness k times smaller than the original one, using a probe with a given geometry where the excitation current with a specified amplitude and frequency runs. If tests within this reduced model are successful then, this paper proves, that it is possible to perform the targeted inspection of the metallic plate to detect a crack having a k times length using a scaled probe increased the same k scale factor with the excitation current increased k times and the frequency reduced k^2 times. Another application of this field dilation invariance can be the use of ECM for the characterization of the microstructure transformation that occurs in the reforming furnace columns used in the petroleum refineries. Again the idea is to evolve from successful tests performed at the laboratory with a coil with reduced dimensions to the inspection of large tubes using a scaled coil that keeps the magnetic field invariant in the scaled domain.---This work was developed under the Instituto de Telecomunicações projects EvalTubes and supported by the Portuguese Science and Technology Foundation (FCT) projects: PEst-OE/EEI/LA0008/2013, SFRH/BD/81856/2011 and SFRH/BD/81857/2011. This support is acknowledged.

9:10 AM

Analyzing Dielectrical Properties of Resins and CFRP with High-Frequency Eddy Current Device Technology

---**Simone Gäbler**, Leibniz Institute of Polymer Research, Department for Composite Materials, Dresden, Germany; Henning Heuer, Fraunhofer Institute for Ceramic Technology and Systems, Department for Sensors and Sensor Systems, Dresden, Germany

---Eddy current testing is well established for non-destructive characterization of electrical conductive materials [1]. The development of high-frequency eddy current technology (with frequency ranges up to 100 MHz) made it even possible to extend the classical fields of application towards less conductive materials like CFRP [2]. The increasing use of high-frequency eddy current technology on CFRP also generates a growing number of measurement results, which apparently contain more information than expected (electrical conductivity and permeability of the sample). An explanation for that effect is seen in the capacitive structure of the carbon rovings. This special characteristic of CFRP could be responsible for additional dielectric influences on eddy current measurement signal [3]. However, experimental research shows that this theory needs to be extended. Even without electrical conductive structures selected non-conductive materials can be differentiated by using the change of complex impedance of the probing coil. An explanation for that phenomenon can be found in the Maxwell's equations. They show that the use of high-frequency eddy current technology is also suitable for non-conductive materials. In that case the change of complex impedance of the probing coil contains information on sample permittivity. Those theoretical conclusions are supported by simulation results as well as experimental research. So it could be shown that the change of complex permittivity during cure of the epoxy resin L20 can be measured not only using a capacitive setup but also using a high-frequency eddy current device. If the sample material is electrically conductive, both, permittivity and conductivity influence the complex impedance measured with high-frequency eddy current devices. However, calibration is possible on both dimensions. That allows permittivity characterization of conductive samples and creates new fields of application for eddy current technology, e.g., detecting local curing defects on CFRP (hot spots).

References:

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2. Schulze, M. et al. (2010): High-resolution eddy current sensor system for quality assessment of carbon fiber materials. Microsystem Technologies Vol. 16 (5), 791-797.
3. Lange, R.; Mook, G. (1994): Structural analysis of CFRP using eddy current methods. NDT & E International Vol. 27 (5), 241–248.

9:30 AM

Developments in Near Electrical Resonance Signal Enhancement (NERSE) Eddy-Current Methods

---**Robert R. Hughes** and Steve M. Dixon, Department of Physics, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---In industry, the detection of small defects above a background noise threshold is always a limiting factor. This is true for even the most sensitivity and reliable of NDT techniques. However, defect signals in eddy-current (EC) inspections have the potential to be boosted above noise thresholds by exploiting the near electrical resonance signal enhancement (NERSE) phenomena, resulting from resonant frequency-shifting of an EC system as the coil passes over a defect. Following on from the observation and characterization of this phenomenon, NERSE based EC methods are being investigated and developed for the detection of sub-millimeter surface defects in Aerospace superalloys. This paper discusses current advances in the development of such techniques and explores the potential of NERSE exploitation as well as examining its complications.

9:50 AM

Influence of Inspection Parameters in Crack Depth Measurements Using Potential Drop Method

---David Utrata and Darrel A. Enyart, Iowa State University, Center for NDE, Ames, IA 50011

---When working with industrial clients, the NDE Group of Company Assistance at Iowa State University often straddles the area between research and application. For example, it is well known that the potential drop method may be used for measure crack depth in metallic specimens. But of interest to our manufacturing clientele is how much sample preparation and data interpretation might be needed if they apply a commercially available off-the-shelf (COTS) device to their particular inspection need. In this paper, a commercially available device that used alternating current potential drop (ACPD) to measure crack depth was applied to a variety of samples having known cracks and notches. These included samples with varying contact area geometries and surface conditions, and were intended to simulate the range of demands of industrial conditions for applying such measurements. The results discuss to what degree the industrial user can expect to get meaningful performance out of such test devices under various conditions, and guidelines are offered for surface preparation needed.

10:10 AM

Determination of Crack Depth in Aluminum Using Eddy Currents and GMR Sensors

---**Artur L. Ribeiro**, Dário J. Pasadas, Helena G. Ramos, and Tiago J. Rocha, Instituto de Telecomunicações, IST, Universidade de Lisboa, Portugal

---In this paper we use eddy currents to determine the depth of linear cracks in aluminum plates. A constant field probe is used to generate the spatially uniform excitation field and a single axis giant magneto-resistor (GMR) sensor is used to measure the eddy currents magnetic field. To settle a standard measurement process, linear cracks with different depths were machined in one aluminum plate with 4 mm of thickness. By scanning those cracks the magnetic field components parallel and perpendicular to the crack's line were measured when the eddy currents were launched perpendicularly to the crack's line. It was verified that better results were obtained using the data acquired with the sensor parallel to the crack. These results were used to extract features correlated to the crack's dimensions. The measurements were repeated with the probe on both sides of the plate, corresponding to the characterization of surface and subsurface cracks. All the selected features (maximum amplitude, signal energy), extracted from the perturbation signals were measured as a function of the excitation frequency. Finally, to characterize one crack in a plate of the same thickness and material, the experimental procedure was defined. The plate surface is scanned to detect and locate one crack. The acquired data enables the determination of the crack's length and orientation. A second scanning is performed with the excitation current perpendicular to the crack and the GMR sensing axis parallel to the crack's line. The features extracted from the acquired data were compared with those obtained from the standard measurements and a depth value was determined.---This work was developed under the Instituto de Telecomunicações project EvalTubes and supported in part by the Portuguese Science and Technology Foundation (FCT) projects: PEst-OE/EEI/LA0008/2013, SFRH/BD/81856/2011 and SFRH/BD/81857/2011. This support is gratefully acknowledged.

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QNDE Future Dates and Locations

July 26-31, 2015

42nd Annual Review of Progress in Quantitative Nondestructive Evaluation; incorporating 6th European American Workshop in Reliability in NDE and proceeded by World Federation of NDE Centers Short Course (topic to be confirmed at Board meeting in July, 2014)

Hyatt Regency
Minneapolis, Minnesota

July 25-31, 2016

Georgia Tech Hotel and Conference Center
Atlanta, Georgia

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